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SOILS AND HYDROLOGY

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SOILS

INDEX

SOILS - A PROCEDURE FOR CLASSIFICATION

1. Introduction

The soil is vital to the growth and sustenance of plant life. It is also a valuable structural material. From the standpoint of administering and protecting the public grazing lands, the Bureau is concerned with the forage production capability of the soil and the use of it to construct dams, dikes, and diversions which are required to manage runoff from precipitation.

This discussion will treat Soil as a Structural Material. This treatise is given from the standpoint of classifying what is available and how it can best be used within a given situation and not a narrative on soil science.

2. Soils as a Structural Material

Gravel and sand.--Both of the coarse-grained components of soil (gravel and sand) have essentially the same engineering properties, differing mainly in degree. The division of gravel and sand sizes by the No. 4 sieve is arbitrary and does not correspond to a sharp change in properties. Well-graded, compacted gravels or sands are stable materials. The coarse-grained soils when devoid of fines are pervious, easy to compact, little affected by moisture, and not subject to frost action. Although grain shape and gradation as well as size affect these properties, for the same amount of fines gravels are generally more pervious, more stable, and less affected by water or frost than are sands.

As a sand becomes finer and more uniform, it approaches the characteristics of silt with corresponding decrease in permeability and reduction in stability in the presence of water. Very fine, uniform sands are difficult to distinguish visually from silt. However, dried sand exhibits no cohesion (does not hold together) and feels gritty in contrast to the very slight cohesion and smooth feel of dried silt.

Silt and clay.--Even small amounts of fines may have important effects on engineering properties of the soils in which they are found. As little as 10 percent of particles smaller than the No. 200 sieve size in sand and gravel may make the soil virtually impervious, especially when the coarse grains are well graded. Also, serious frost heaving in well-graded sands and gravels may be caused by less than 10 percent of fines. The utility of coarse-grained materials for surfacing roads can be improved by the addition of a small amount of clay to act as a binder for the sand and gravel particles.

Soils containing large quantities of silt and clay are the most troublesome to the engineer. These materials exhibit marked changes in physical properties with change of water content. A hard, dry clay, for example, may be suitable as a foundation for heavy loads so long as it remains dry, but may turn into a quagmire when wet. Many of the fine soils shrink on drying and expand on wetting, which may adversely affect structures founded on them or constructed of them. Even when moisture content does not change, the properties of fine soils may vary considerably between their natural condition in the ground and their state after being disturbed. Deposits of fine particles which have been

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1. Introduction

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This discussion will treat soil as a structural material. This treatise is given from the standpoint of identifying what is available and how it may best be used without a large sacrifice for what a particular use will achieve.

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Silt and clay.--Even small amounts of fines may have important effects on engineering properties of the soils in which they are found. As little as 10 percent of particles smaller than the No. 200 sieve size in sand and gravel may make the soil virtually impervious, especially when the coarse grains are well graded. Also, serious frost heaving in well-graded sands and gravels may be caused by less than 10 percent of fines. The quality of coarse-grained materials for surfacing roads can be improved by the addition of a small amount of clay to act as a binder for the sand and gravel particles.

Soils containing large quantities of silt and clay are the most troublesome to the engineer. These materials exhibit marked changes in physical properties with change of water content. A hard, dry clay, for example, may be suitable as a foundation for heavy loads so long as it remains dry, but may turn into a quagmire when wet. Many of the fine soils shrink on drying and expand on wetting, which may adversely affect structures founded on them or constructed of them. Even when moisture content does not change, the properties of fine soils may vary considerably between their natural condition in the ground and their state after being disturbed. Deposits of fine particles which have been

subjected to loading in geologic time frequently have a structure which gives the material unique properties in the undisturbed state. When the soil is excavated for use as a construction material or when the natural deposit is disturbed by driving piles, for example, the soil structure is destroyed and the properties of the soil are changed radically.

Silts are different from clays in many important respects, but because of similarity in appearance, they often have been mistaken one for the other, sometimes with unfortunate results. Dry, powdered silt and clay are indistinguishable, but they are easily identified by their behavior in the presence of water. Recognition of fines as being silt or clay is an essential part of the Unified Soil Classification System.

SILTS are the nonplastic fines. They are inherently unstable in the presence of water and have a tendency to become "quick" when saturated. Quick silts are called "bulls liver" by construction men. Silts are fairly impervious, difficult to compact, and are highly susceptible to frost heaving. Silt masses undergo change of volume with change of shape (the property of dilatancy) in contrast to clays which retain their volume with change of shape (the property of plasticity). The dilatancy property, together with the "quick" reaction to vibrations, affords a means of identifying typical silt in the loose, wet state. (See dilatancy test on the classification chart, figure 3.) When dry, silt can be pulverized easily under finger pressure (has very slight dry strength), and will have a smooth feel between the fingers in contrast to the grittiness of fine sand.

Silts differ among themselves in size and shape of grains which are reflected mainly in the property of compressibility. For similar conditions of previous loading, the higher the liquid limit of a silt the more compressible it is. The liquid limit of a typical bulky-grained inorganic silt is about 30 percent, while highly micaceous or diatomaceous silts (so-called "elastic" silts) consisting mainly of flaky grains, may have liquid limits as high as 100 percent. The differences in quicking and dilatancy properties afford a means of distinguishing in the field between silts of low liquid limit (symbol L) and those of high liquid limit (symbol H).

CLAYS are the plastic fines. They have low resistance to deformation when wet, but they dry to hard cohesive masses. Clays are virtually impervious, difficult to compact when wet, and impossible to drain by ordinary means. Large expansion and contraction with changes in water content are characteristics of clays. The small size, flat shape, and mineral composition of clay particles combine to produce a material that is both compressible and plastic. The higher the liquid limit of a clay, the more compressible it will be when compared at equal conditions of previous loading; hence, in the Unified Soil Classification System, the liquid limit is used to distinguish between clays of high compressibility (symbol H) and those of low compressibility (symbol L). Differences in plasticity of clays are reflected by their plasticity indexes. At the same liquid limit, the higher the plasticity index the more cohesive is the clay. Field differentiation among clays is accomplished by the toughness test in which the moist soil is molded and rolled into threads until crumbling occurs and by the dry strength test which measures the resistance of the clay to breaking and pulverizing. With a little experience in performing these tests, the clays of low compressibility and low plasticity, "lean" clays (symbol LO, can be readily distinguished from the highly plastic, highly compressible "fat" clays (symbol H).

Sediments and deposits of geologic time frequently have a structure which gives the material higher resistance in the undisturbed state. When the soil is excavated and used as a construction material or when the natural deposit is disturbed by driving piles, for example, the soil structure is destroyed and the properties of the soil are changed radically.

Silts are different from clays in many important respects, but because of similarity in appearance, they often have been mistaken one for the other, sometimes with unfortunate results. Dry, powdered silt and clay are indistinguishable, but they are easily identified by their behavior in the presence of water. Recognition of fines as being silt or clay is an essential part of the Unified Soil Classification System.

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Silts differ among themselves in size and shape of grains which are reflected mainly in the property of compressibility. For similar conditions of previous loading, the higher the liquid limit of a silt the more compressible it is. The liquid limit of a typical bulky-grained inorganic silt is about 35 percent, while highly micaceous or diatomaceous silts (so-called "elastic" silts) consisting mainly of flaky grains, may have liquid limits as high as 100 percent. The differences in quantity and effective properties affords a means of distinguishing, in the field between silts of low liquid limit (symbol L) and those of high liquid limit (symbol H).

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Organic matter.--Organic matter in the form of partly decomposed vegetation is the primary constituent of peaty soils. Varying amounts of finely divided vegetable matter are found in plastic and nonplastic sediments, and often affect their properties sufficiently to influence their classification. Thus we have organic silts and silt-clays of low plasticity and organic clays of medium to high plasticity. Even small amounts of organic material in colloidal form in a clay will result in an appreciable increase in liquid limit of the material without increasing its plasticity index. Organic soils are dark gray or black in color, and usually have a characteristic odor of decay. Organic clays feel spongy in the plastic range as compared to inorganic clays. The tendency for soils high in organic content to create voids by decay or to change the physical characteristics of a soil mass through chemical alteration makes them undesirable for engineering use. Soils containing even moderate amounts of organic matter are significantly more compressible and less stable than inorganic soils; hence, they are less desirable for engineering use.

3. Unified Soil Classification System

In 1952, the Bureau of Reclamation and the Corps of Engineers, with Professor Casagrande as consultant, reached agreement on a modification of Professor Casagrande's airfield classification, which they named the Unified Soil Classification System. The system takes into account the engineering properties of soils; it is descriptive and easy to associate with actual soils; and it has the flexibility of being adaptable both to the field and to the laboratory. Probably its greatest advantage is that a soil can be classified readily by visual and manual examination. The Unified Classification System is based on size of particles, the amounts of various sizes, and characteristics of the very fine grains. The Bureau of Land Management uses this system in classifying soil samples in foundations and borrow area investigations. This discussion deals specifically with the classification of soils by this system.

The Unified Soils Classification System establishes 15 soil groups for classifying soils. The typical names and symbol for each group are given in the classification chart, Figure 1. The immediate objective of soil classification is to assign to a soil one of the standard group names, and by descriptive words and phrases, distinguish that soil from other soils in the same group.

4. Equipment Needed for Soils Classification and Testing

1.	Proctor compaction set consisting of: 1/30 cu. ft. compaction mold with plate and collar Compaction hammer and guide (5.5# - 12" drop)
1. (alternate)	Proctor compaction set consisting of: 1/20 cu. ft. compaction mold with plate and collar Compaction hammer and guide (5.5# - 18" drop)
2.	Proctor needle tester and needles
3.	Sand cone device with plate (1 gal capacity, 6½" cone)
3. (alternate)	1/20 cu. ft. Volumeasure, field plate and 12 space balloons.
4.	2000 Gram Beam balance with set of weights and carrying case (accurate to 0.1 gram)

5. Platform field scale (40# capacity, accurate to .01#)
6. Portable field oven
7. Field Stove
8. Sampling spoon
9. 1 inch steel chisel
10. Rubber mallet
11. 12 inch straight edge
12. Mixing trowel
13. Laboratory tongs
14. Wide end trimming spatula
15. Cement-mold brush (brass)
16. Sand scoop
17. 2 cement pans, tapered, 24" by 24" x 3" deep
18. 6 rectangular mixing pans, 5" x 16" x 5" deep
19. 3 doz tin sample boxes with covers, 8 oz. size
20. 2 doz aluminum moisture boxes with covers, 3½ dia., 2" deep
21. ½ doz soil sample cans with lids, 1 gal size
22. Graduated cylinder, 250 ml
23. Aluminum beaker, 60 ml
24. Aluminum beaker, 500 ml
25. Hand operated Sieve Shaker and U. S. Standard Sieves, 8 inch dia. as follows:

No. 4	No. 40
No. 8	No. 50
* No. 16	No. 100
* No. 30	

26. Screens

    3"
    1"
    ½"

27. Two 8-inch brasspans and 1 cover for U. S. Standard sieves
28. ¼-inch sieve - 18 inch dia.
29. Sand - a supply of clean, air dry, uniformly graded sand passing the No. 16 sieve and retained on the No. 30 sieve. Clean "blow sand" or clean dune sand is often suitable.
30. Wet washing sieve No. 200 - 8 in. dia., 4 in. deep
31. Fine sieve brush
32. Quartering canvas
33. Metal thermometer - 50° to 300° F
34. Drive hammer and 1/2 dozen drive cylinders (See Illustration)

* For screening sand for use in the density cone.

Additional equipment for Atterberg Tests

35. ASTM liquid limit set consisting of:
Standard liquid limit device and tool
Mixing dish
Flexible spatula
100 cc graduated cylinder
2 doz. moisture content cans

36. Plastic limit set consisting of:
Plastic limit plate
Mixing dish
Flexible spatula
25 ml glass graduate
1 doz - 2 oz moisture cans

37. Battery Filler
38. Soil mortar
39. Soil pestle
40. Porcelain crucibles
41. Sodium silicate solution
42. PH Test Set

5. Visual and Manual Classification

This method employs simple manual tests and visual observations to estimate the size and distribution of the coarse grained soil fractions and to indicate the plasticity characteristics of the fine grained fractions. This method is used predominantly for field classification work.

Equipment useful in making the usual classification is: (1) a rubber syringe or small oil can having a capacity of approximately ½ pint, (2) supply of clean water, (3) a small bottle of diluted hydrochloric acid (about 10%), and (4) a classification chart, Figure 1.

STEP ONE - Select a representative sample of soil from each soil stratum in the soil profile encountered in foundation or borrow area explorations and spread it on a flat surface.

STEP TWO - Remove all particles larger than 3 inches from the sample. Estimate the percentage of this fraction of the sample by either weight or volume. Record this percentage on Illustration 1, % greater than 3". Keep in mind that under the Unified Soil Classification System only that fraction of the sample smaller than 3 inches is classified.

STEP THREE - Estimate the percentage by weight of individual particles which can be seen by the unaided eye. If it contains more than 50 percent visible particles, the sample is classified coarse grained. If the sample contains less than 50 percent visible particles, it is classified fine grained. Record the classification on Illustration 1. This classification is the basis for further visual analysis of the sample. For classification purposes, the No. 200 sieve size is the particle size division between fine and coarse grained particles. Particles of this size are about the smallest that can be seen individually by the unaided eye.

Through this three-step procedure, the first determination in the classification system has been made. That is, the sample is either a fine or coarse grained soil. The procedure for classifying each of these fractions is given below. Use chart, Figure 1, to aid in a further classification of the soil sample.

COARSE GRAINED (G) SOIL SAMPLE CLASSIFICATION

STEP ONE - The coarse grain soil sample is further identified by estimating the percentage of (1) gravel size particles, size range 3 inches to the No. 4 sieve (about ¼ inch), (2) sand size particles, size range No. 4 sieve to No. 200 sieve, and (3) silt and clay sized particles, size range smaller than No. 200 sieve in the sample. The fraction of a soil smaller than the No. 200 sieve size (silts and clays) is referred to as "fines". Record the finding on Illustration 1.

STEP TWO - This step is to classify and describe the coarse grain sample by symbol. Chart No. 1 gives 8 group symbols for classifying coarse grained soil. Each symbol describes a specific type of coarse grain soil. Compare information obtained in STEP ONE with the chart Figure 1, Coarse Grain Sample.

If the percentage of gravel is greater than the sand, the soil sample is a gravel (G). Analyze the gravel sample for gradation, grain shape, and content of "fines". By comparison, select the gravel group from chart Figure 1 to which it conforms. Identify the group by the symbol GW, GM, etc. and record on Illustration 1 in the group symbol column.

If the percentage of sand is greater than the gravel, the soil sample is a sand (S). Analyze the sand for gradation, grain shape, and content of "fines". By comparison select the sand group from chart Figure 1 to which it conforms. Identify the group by the symbol SW, SP, etc., and record on Illustration 1 in the group symbol column.

FINE GRAINED SOIL SAMPLE CLASSIFICATION

The fine grained soil sample is identified by estimating the (1) percentage of gravel size particles, (2) sand sized particles, and (3) silt and clay sized particles in it, and performing the manual identification tests for dry strength, dilatance, and toughness.

STEP ONE - Analyze the soil sample by estimating the percentage of gravel size particles, sand size particles and fines (smaller than 200 sieve) and record on Illustration 1.

STEP TWO - It has been previously stated that soil particles smaller than No. 200 sieve are referred to as "fines". In this use, "fines" refer to clays and silts. The dilatance, dry strength, toughness, acid and shine tests are performed on the fines. Fines as used in statement with reference to these tests include sands smaller than No. 40 sieve (1/64 inch).

Select a small representative sample and remove all particles larger than the No. 40 sieve. Take from the sample two small specimens, each with a volume of about ½ cubic inch. Prepare these by moistening until they can be easily rolled into a ball. (An experienced operator may be able to perform all the tests with one ball, but it is general practice to prepare two). Perform the following test, carefully observing the behavior of the soil specimen during each test.

<u>STEP THREE</u> - <u>The (Dilatance) Shake Test</u> - This test indicates the reaction of the soil specimen to shaking. Add enough water to nearly saturate one of the soil pats.

Place the pat in the open palm of one hand and shake horizontally, striking vigorously against the other hand several times. Squeeze the pat between the fingers.

The appearance and disappearance of the water with shaking and squeezing is referred to as a reaction. This reaction is called quick if water appears and disappears rapidly, slow if water appears and disappears slowly, and no reaction if the water condition does not appear to change. Observe and record the type of reaction on Illustration 1.

<u>Rapid reaction</u> indicates a lack of plasticity, such as is the case with a typical inorganic silt, rock flour, or a fine sand.
<u>Slow reaction</u> indicates a slightly plastic silt or silty clay.
<u>No reaction</u> indicates a clay or a peaty (organic) material.

<u>STEP FOUR</u> - <u>Toughness Test</u> - This test indicates the consistency of the soil specimen near the plastic limit condition. Dry the pat used in the dilatancy test by working and molding until it has the consistence of putty. The time required to dry the pat is an indication of its plasticity. Roll the pat on a smooth surface or between the palms into a thread about 1/8 inch in diameter.

Fold and reroll the thread repeatedly to 1/8 inch diameter so that its water content is gradually reduced until the 1/8 inch thread just crumbles.

The water content at this time is called the plastic limit, and the resistance to molding at the plastic limit is called the toughness.

After the thread crumbles, the pieces should be lumped together and a slight kneading action continued until the lump crumbles. High-plasticity clays form a tough thread which can be remolded into a lump below the plastic limit and deformed under high finger pressure without crumbling.

<u>Medium-plasticity</u> soil forms a medium tough thread, but the lump crumbles soon after the plastic limit is reached.
<u>Low-plasticity</u> soil forms a weak thread that cannot be lumped together below the plastic limit. Plastic soils containing organic material or much mica form threads which are very soft and spongy.

Select a small representative sample and remove all particles larger than the No. 40 sieve. Thoroughly mix and separate two small specimens, each with a volume of about 1 cubic inch. Dampen these by remixing until they can be easily rolled into a ball. The experienced operator may be able to perform all the tests with one ball, but it is general practice to conduct them in a definite sequence, carefully observing the behavior of the soil specimens during each test.

Shaking Test (Dilatancy) (Reaction to Shaking). This test indicates the reaction of the soil to shaking or squeezing. Add enough water to nearly saturate one of the small pats.

Place the pat in the open palm of the hand and shake horizontally, striking vigorously against the other hand several times. Squeeze the pat between the fingers.

The appearance and disappearance of the water with shaking and squeezing is referred to as a reaction. This reaction is called quick if water appears and disappears rapidly. Slow if water appears and disappears slowly, and no reaction if the water condition does not appear to change. Observe and record the type of reaction as illustration 7.

Quick reaction indicates a lack of plasticity, such as in the case with a typical inorganic silt, rock flour, or a fine sand.
Slow reaction indicates a slight to medium plastic silt or clay.
No reaction indicates a clay or a highly plastic material.

Dry Strength (Crushing Characteristics). This test determines the consistency of the soil specimen near the plastic limit of soils. Roll the pat until it has the thickness of a pencil, and the soil is mostly dry. Break it and note the appearance of cracks. The time required to air dry the pat is an indication of the plasticity. When the pat is dry, attempt to crumble the pats into a powder between the fingers.

This can result the finer characteristics of the dried specimen so that its water content is gradually reduced until the 1/8 inch threads just crumble.

The water content at this time is called the plastic limit, and the resistance to molding at the plastic limit is called the toughness.

After the thread crumbles, the pieces should be lumped together and a slight kneading action continued until the lump crumbles. Highly plasticity clays have a higher tough which can be retained into a lump below the plastic limit and withstand considerable finger pressure without crumbling.

Medium plasticity soil forms a medium tough thread, but the lump crumbles soon after the plastic limit is reached.
Low plasticity soil forms a weak thread that can not be lumped together below the plastic limit. Plastic soils containing organic material or much mica form threads which are very soft and spongy.

<u>Non-plastic</u> soils cannot be rolled into a thread of 1/8 inch diameter at any water content. Observe and record the toughness of the soil specimen on Illustration 1.

<u>STEP FIVE</u> - <u>Dry Strength Test</u> - This test indicates the resistance of the soil sample specimen to crushing, which is a measure of its cohesiveness. Completely dry one of the prepared specimens. Then crush it between the thumb and fingers.

The pressure required to crumble it is a measure of its resistance to crushing, and indicates its cohesiveness.

<u>High dry strength</u> indicates a highly plastic, inorganic clay. The dried sample can be broken but cannot be powdered by finger pressure. Observe the reaction of the specimen under test and record the dry strength in Illustration 1.
<u>Medium dry strength</u> indicates a low to medium plastic inorganic clay. Considerable finger pressure is required to powder the sample.
<u>Slight dry strength</u> indicates an inorganic silt, a rock flour, or silty sand. However, the sand feels gritty when sample is powdered.

<u>STEP SIX</u> - <u>Organic Content and Color</u> - Fresh, wet organic soils usually have a distinctive odor of decomposed organic matter. This odor can be made more noticeable by heating a wet sample. Another indication of the organic material is the distinctive dark color. Dry inorganic clays develop an earthy odor upon moistening which is distinctive from that of decomposed organic matter. Record results on Illustration 1.

<u>STEP SEVEN</u> - <u>The Acid Test</u> - A diluted solution of hydrochloric acid (HCL) is used primarily to determine the presence of calcium carbonate. For soils with high dry strength, a strong reaction when the acid is applied indicates that the strength may be due to calcium carbonate as a cementing agent rather than colloidal clay. Record results of this test on Illustration 1.

<u>STEP EIGHT</u> - <u>The Shine Test</u> - This is a quick supplementary procedure for determining the presence of clay in the sample. The test is performed by cutting a lump of dry or slightly moist soil with a knife. A shiny surface imparted to the soil indicates highly plastic soil, while a dull surface indicates low plasticity. Record results on Illustration 1.

<u>STEP NINE</u> - This step is to classify and describe the fine grain soil by Symbol Chart No. 1, which gives 6 group symbols. Each symbol describes a specific type of fine grain soil. Compare information in STEP ONE through FIVE with Chart No. 1, Fine Grain Soil. Select the group symbol from Chart No. 1, Fine Grain Soil, whose description conforms most nearly to the sample under test. Record symbol on Illustration 1.

6. <u>Laboratory Classifications of Soils</u>

The Unified Soil Classification System provides for precise delineation of the soil groups by using results of laboratory tests. Classifying by

Non-plastic soils cannot be rolled into a thread of 1/8 inch diameter at any water content. Observe and record the toughness of the soil specimen on Illustration 4.

Dry Test - Dry Strength Test - This test indicates the resistance of the soil sample specimen to crumbling, which is a measure of its cohesiveness. Completely dry one of the prepared specimens. Then crush it between the thumb and fingers.

The pressure required to crumble it is a measure of its resistance to crumbling, and indicates its cohesiveness.

High dry strength indicates a highly plastic inorganic clay. The dried sample can be broken but cannot be powdered by finger pressure. Observe the reaction of the specimen under test and record the dry strength in Illustration 4.
Medium dry strength indicates a low to medium plastic inorganic clay. Considerable finger pressure is required to powder the sample.
Slight dry strength indicates an inorganic silt, a rock flour, or silty sand. However, the sand feels gritty when sample is powdered.

Odor Test - Organic Content and Color - Fresh, wet organic soils usually have a distinctive odor of decomposed organic matter. This odor can be made more noticeable by heating a wet sample. Another indication of the organic material is the distinctive dark color. Dry inorganic clays develop an earthy odor upon moistening which is distinctive from that of decomposed organic matter. Record results on Illustration 4.

Acid Test - The Acid Test - A dilute solution of hydrochloric acid (HCl) is used primarily to determine the presence of calcium carbonate. For soils with high dry strength, a violent reaction when the acid is applied indicates that the strength may be due to calcium carbonate as a cementing agent rather than colloidal clay. Record results of this test on Illustration 4.

Shine Test - The Shine Test - This is a quick supplementary procedure for determining the presence of clay in the sample. The test is performed by cutting a lump of dry or slightly moist soil with a knife. A shiny surface imparted to the soil indicates highly plastic soil, while a dull surface indicates low plasticity. Record results on Illustration 4.

Fine Soils - This step is to classify and describe the fine grain soil by symbol. There are 6 major fine grain groups symbols. Each symbol describes a specific type of fine grain soil. Compare information on your own findings with data sheet No. 4, Fine Grain Soils. Select the group symbol from data sheet No. 4, Fine Grain Soils, whose description conforms most nearly to the sample under test. Record symbol on Illustration 4.

B. Laboratory Identification of Soils

The Unified Soil Classification System provides for precise delineation of the soil groups by using results of laboratory tests. Classification by

these tests alone does not fulfill the requirements for complete classification, as it does not provide an adequate description of the soil. Therefore, the descriptive information required for the visual method should also be included in the laboratory classification.

A. Gradation - Sieve Analysis

Take a representative sample of the soil to be tested. The size of the sample depends on type of soil. The size of sample is as follows:

Fine grained soil	100 to 200 grams
Sandy soil	200 to 500 grams
Gravelly soil	1 to 4 kilograms

A sieve analysis is made either on the entire sample or on the sample after the fines are removed by washing. Determine if prewashing is required. If this cannot be determined by visual inspection, oven-dry a moist pat of the material and then examine its dry strength by breaking it up between the fingers. If it can be easily crushed and the fine material powdered by finger pressure, then the sieve analysis can be made without prewashing.

Prewashing not required

STEP ONE - Oven dry the sample

STEP TWO - Weigh sample after cooling and record weight to nearest gram on Illustration 2.

STEP THREE - Break up lumps of material by rolling with improvised rolling pin on clean, smooth surface. Powder fine material with rubber-covered pestle until thoroughly pulverized.

STEP FOUR - Pass sample through a 3" screen to remove particles larger than 3 inches, a 1" screen to remove particles larger than 1 inch, a ½" screen to remove particles larger than ½ inch and a No. 4 sieve to remove particles larger than will pass this sieve. These sieves may be stacked, and screening done in one operation. Weigh fraction of sample retained on each screen and record on Illustration 2.

STEP FIVE - Transfer the fraction of the sample which passed the No. 4 sieve to a set of sieves (Nos. 8, 16, 30, 50, 100 and 200) stacked with No. 4 sieve on top and No. 200 sieve on bottom. Place cover on top and shake the stack vigorously with a horizontal rotating motion. The shaking period depends on the amount of fine material in the sample. Weigh and record the amount of soil retained on each sieve and the fraction of soil passing the No. 200 sieve and record same on Illustration 2.

Prewashing required

STEP ONE - Oven dry the sample

STEP TWO - Weigh sample after cooling and record weight on Illustration 2.

STEP THREE - Break up lumps of material by rolling with improvised rolling pin on clean, smooth surface. Powder fine material with rubber-covered pestle until thoroughly pulverized.

STEP FOUR - Transfer the sample to a pan, add enough water to cover the material and let soak until all material is disintegrated. This may require from 2 to 12 hours.

STEP FIVE - Place the soaked sample on a No. 200 sieve and wash it until all particles smaller than No. 200 sieve has passed through the No. 200 sieve. Loss of soil from the sample during this operation must be avoided.

STEP SIX - Oven dry the washed sample retained on the No. 200 sieve and reweigh. Record on Illustration 2.

STEP SEVEN - Pass washed and oven dried sample through a 3" screen to remove particles larger than 3 inches, a 1" screen to remove particles larger than 1 inch, a ½" screen to remove particles larger than ½ inch, and a No. 4 sieve to remove particles larger than this sieve. These screens or sieves may be stacked and screening done in one operation. Weigh fraction of sample retained on each screen and record on Illustration 2.

STEP EIGHT - Transfer the fraction of the sample which passed the No. 4 sieve to a set of sieves (Nos. 8, 16, 30, 50, 100 and 200) stacked with No. 8 on top and No. 200 on bottom. Place cover on top and shake the stack vigorously with a horizontal rotating motion. Weigh the fraction of the sample retained on each screen and the fraction passing the No. 200 sieve. Record the weights on Illustration 2.

STEP NINE - The weight of the sample smaller than No. 200 sieve is the difference in weight between the original sample and the oven-dried washed sample retained on sieves 3" through No. 200, plus small fraction of sample passing the No. 200 sieve, if any.

STEP TEN - Add the weights retained on each sieve and check this total against the weight of the dry sample. If error exceeds about 3% reweigh each fraction or repeat the test. If error is less than 3%, apply numerical value of error to weight of largest fraction of the sample.

STEP ELEVEN - Compute the weight of material passing each sieve.
Example:

Weight passing No. 4 sieve = wt. of the dry sample minus (-) wt. of material retained on No. 4 and all larger sieves.

Record weights on Illustration 2.

STEP TWELVE - Compute the percentage by weight of material passing each sieve. Example:

$$\text{Percentage by wt.} = 100 \times \frac{\text{Wt. passing No. 4 sieve}}{\text{Wt. of dry sample}}$$

Record the percentage on Illustration 2.

STEP THIRTEEN - Plot the grain-size distribution curve on Illustration 2A.

B. The Atterberg Tests

The liquid limit, plastic limit, and shrinkage limit of soil, from which the plastic index and shrinkage factors are obtained, are determined by the Atterberg Test.

The LIQUID LIMIT of soil is that moisture content, expressed as a percentage of the weight of the oven-dried soil, at which the soil will just begin to flow when lightly jarred 25 times. The test is made as follows:

STEP ONE - The liquid limit device is adjusted so that the point on the cup which comes in contact with the base is exactly 1 cm. (0.3937 in.) above the base. The handle end of the grooving tool is ground to 1 cm. and is used to set the liquid limit device so that the cup will rise exactly this distance above the base.

STEP TWO - Take a representative sample of soil which passed the No. 4 sieve and air-dry it.

STEP THREE - Use a No. 40 sieve to screen the test sample. A mortar and rubber-tipped pestle may be used to pulverize the hard lumps. Care is taken not to crush the individual soil particles.

STEP FOUR - Thoroughly mix the soil which passes the No. 40 sieve and take a 100 gram air-dried representative sample of it. Place this test sample in an evaporating dish of known weight and thoroughly mix with water (preferably distilled) for a putty-like consistence. Record the weight of the dry and wet soil and the water on Illustration 3. Compute the percentage of moisture in the sample, which is:

$$\text{Percentage of moisture} = \frac{\text{weight of water}}{\text{weight of dry soil}} \times 100$$

STEP FIVE - Place a portion of this sample in the brass cup of the liquid limit device.

Level off the cup sample at a depth of 1 cm. and divide it with the grooving tool along the diameter through the center line of the cam follower.

STEP SIX - Turn the crank of the liquid limit device at a rate of two rotations per second. The cup shall be lifted and dropped until the two sides of the sample come into contact at the bottom of the groove

STEP TWELVE - Compute the percentages by weight of material passing each sieve. Example:

$$\text{Percentage by wt.} = \frac{\text{Wt. passing No. X sieve}}{\text{Wt. of dry sample}} \times 100$$

Record the percentage on Illustration 3.

STEP THIRTEEN - Plot the grain-size distribution curve on Illustration 3A.

B. THE ATTERBERG TESTS

The liquid limit, plastic limit, and shrinkage limit of soil, from which the plastic index and shrinkage indices are obtained, are determined by the Atterberg test.

The liquid limit of soil is that moisture content, expressed as a percentage of the weight of the oven-dried soil, at which the soil will just begin to flow when lightly jarred 25 times. The test is made as follows:

STEP ONE - The liquid limit device is adjusted so that the point on the cup which comes in contact with the base is raised 1 cm. (0.3937 in.) above the base. The handle end of the grooving tool is gauged to 1 cm. and is used to set the liquid limit device so that the cup will rise exactly this distance above the base.

STEP TWO - Take a representative sample of soil which passed the No. 4 sieve and air-dry it.

STEP THREE - Use a No. 40 sieve to screen the soil sample. A mortar and rubber-tipped pestle may be used to pulverize the soil sample. Care is taken not to break the individual soil particles.

STEP FOUR - Thoroughly mix the soil which passed the No. 40 sieve and take a 100 gram air-dried sample and weigh it. Place this sample in an evaporating dish and thoroughly mix it with water (preferably distilled) for a period of about ten minutes. Record the weight of the dry and wet soil and the water on Illustration 3. Compute the percentage of moisture in the sample, as follows:

$$\text{Percentage of moisture} = \frac{\text{Weight of water}}{\text{Weight of dry soil}} \times 100$$

STEP FIVE - Place a portion of this sample in the brass cup of the liquid limit device.

Level off the cup sample at a depth of 1 cm. and divide it with the grooving tool along the diameter through the center line of the cam follower.

STEP SIX - Turn the crank of the liquid limit device at a rate of two rotations per second. The cup should be lifted and dropped until the two sides of the sample come into contact at the bottom of the groove.

along a distance of about ½ inch. Record the number of blows required for the divided soil to make this contact on Illustration 3. Steps 4, 5, and 6 on 4 and 5 samples are repeated with samples of the soil at 3 or more additional moisture contents both above and below that requiring 25 blows for closure of the groove. Record results.

STEP SEVEN - Plot a "flow curve" representing the relation between moisture contents and corresponding numbers of blows on semilogarithmic graph paper. The moisture content is plotted as irdinate on the arithmetical scale and the number of blows as abscissa on the logarithmic scale, Illustration 4.

The moisture content, expressed as a percentage of the weight of the oven-dried soil, at the intersection of the flow curve with the 25 blow line is the liquid limit of the soil. Place the sample in a can of known weight. Weigh the can and wet sample. Oven dry the sample at 220° - 250° F until no difference in weight can be measured with scales. (Can must be covered and cooled to room temperature before weighing) Weigh the can and dry sample. Compute the weight of water and the moisture content in percentage.

$$\frac{\text{Weight of water}}{\text{Weight of oven dried soil}} \times 100 = \text{moisture content}$$

Use Illustration 3 in making the test.

C. The PLASTIC LIMIT of a soil is the lowest water content, expressed as a percentage of the weight of the oven-dried soil, at which the soil can be rolled into threads 1/8 inch in diameter without the threads breaking into pieces.

STEP ONE - Take a representative 15 gram sample of the air dried soil passing the No. 40 sieve and place it in an evaporating dish.

STEP TWO - Mix the sample with distilled water until the mass becomes sufficiently plastic to be easily shaped into a ball.

STEP THREE - Roll the ball of soil between the palm of the hand and the ground glass plate or piece of paper with just sufficient pressure to form the soil mass into a thread.

When the diameter of the resulting thread becomes 1/8 inch, the soil is kneaded together to form a ball and again rolled into a thread. This process is continued until the soil crumbles when the thread becomes 1/8 inch in diameter and the crumbled pieces of the thread cannot be reformed into a ball.

STEP FOUR - Weigh the dish. Place the sample in the dish and weigh the dish and wet sample. Oven dry the wet sample after which weigh the dish and dry sample. Use Illustration 3 for recording results. Compute the weight of the moisture and the dry soil. The weight of the water = the weight of the dish and wet soil - the weight of the dish and dry soil. The weight of the dry soil = the weight of the dish and dry soil - the weight of the dish.

along a distance of about ½ inch. Record the number of blows required for the divided soil to make this contact as illustration 4. Steps 4, 5, and 6 to 8 are then repeated with samples of the soil at 3 or more additional water contents so that one has more than requiring 25 blows for closing of the groove. Record results.

FLOW CURVE - Plot a "flow curve" representing the relation between moisture content and corresponding number of blows on semilogarithmic graph paper. The moisture content is plotted as ordinate on the arithmetical scale and the number of blows as abscissa on the logarithmic scale. (Illustration 5)

The moisture content, expressed as a percentage of the weight of the oven-dried soil, at the intersection of the flow curve with the 25 blow line is the liquid limit of the soil. Place the sample in a can of known weight. Weigh the can and wet sample. Oven dry the sample at 220° - 230° F until no difference in weight can be detected with another weigh, (can must be covered and cooled to room temperature before weighing). Weigh the can and dry sample. Compute the weight of water and the moisture content in percentage.

$$\frac{\text{Weight of water}}{\text{Weight of oven dried soil}} \times 100 = \text{Moisture content percent}$$

See illustration 6 to compute the test.

C) The PLASTIC LIMIT of a soil is the lowest water content, expressed as a percentage of the weight of the oven dried soil, at which the soil can be rolled into threads 1/8 inch in diameter without the threads crumbling into pieces.

PREPARE - Take a representative sample, some 20 grams of the air dried soil passing the No. 40 sieve and place it in a evaporating dish.

ADD WATER - Add distilled water until the soil becomes sufficiently plastic to be easily shaped into a ball.

ROLL THREAD - Roll the ball of soil between the palm of the hand and the ground glass plate or piece of paper with just sufficient pressure to roll the soil into a thread.

When the diameter of the thread is reduced to about 1/8 inch, the soil is broken, kneaded into a ball and again rolled into a thread. This process is continued until the soil crumbles when the thread becomes 1/8 inch in diameter and the crumbled pieces of the thread cannot be re-rolled into a ball.

MOISTURE - Weigh the dish. Place the sample in the dish and weigh the dish and the sample. Oven dry the wet sample after 4 hrs weigh the dish and dry sample, see illustration 7 for computing the value. Compute the moisture content of the dry soil. The weight of the water = the weight of the dish and wet soil - the weight of the dish and dry soil. The weight of the dry soil = the weight of the dish and dry soil - the weight of the dish.

Compute

The water content expressed as a percentage of the weight of the oven dried soil.

$$\text{PLASTIC LIMIT} = \frac{\text{weight of water}}{\text{weight of oven dried soil}} \times 100$$

Record on Illustration 3.

PLASTIC INDEX of a soil is the difference between its liquid limit and its plastic limit and shall be calculated as follows:

Plasticity index = liquid limit - plastic limit

D. Compaction and Penetration Resistance

This test determines the relationships between the moisture content of the soil and the resulting density and firmness when the soil is compacted as described below.

STEP ONE - Screen the soil material through a No. 4 sieve and thoroughly mix the fraction passing the No. 4 sieve.

STEP TWO - Take a 40 pound representative sample of the material passing the No. 4 sieve and put it into the large drying tray.

STEP THREE - Mix the 40 pound sample thoroughly with enough water to cause the soil to adhere or ball together slightly when squeezed firmly in the hand.

STEP FOUR - Place this material in an air tight container and store it at least 24 hours to permit moisture to become uniform throughout the sample. The storage period may be reduced or even omitted on soils to which only a small amount of additional water is added, or on soils which readily absorb moisture.

STEP FIVE - Weigh and record the weight of laboratory compaction cylinder (cylinder only).

STEP SIX - Attach cylinder with collar to base plate.

STEP SEVEN - Place approximately 7 pounds of the moist sample into a mixing pan, mix, and place a sufficient amount in compaction cylinder or mold to yield approximately 2-inch compacted layer. During compaction, the mold shall rest firmly on a uniform, rigid foundation, equivalent to a 200 pound block of concrete.

STEP EIGHT - Place the tamping rod in the gage and compact the material in the mold with 25 blows, uniformly distributed over the area. Use a full drop for each blow.

STEP NINE - Repeat step eight for the second and third layers. The third layer should extend slightly above the top of the cylinder to allow for trimming to top the sample.

Example
The water content expressed as a percentage of the weight of the oven dried soil.

PLASTIC LIMIT = $\dfrac{\text{WEIGHT OF WATER}}{\text{Weight of oven dried soil}} \times 100$

Record on Illustration 3.

PLASTIC INDEX of a soil is the difference between its liquid limit and its plastic limit and shall be calculated as follows:

Plasticity index = liquid limit - plastic limit

D. Compaction and Moisture-Density Relationship

This test determines the relationship between the moisture content of the soil and the resulting density and [illegible] when the soil is compacted as specified below.

STEP ONE - Screen the soil material through a No. 4 sieve and thoroughly mix the fraction passing the No. 4 sieve.

STEP TWO - Take a 6½ pound representative sample of the material passing the No. 4 sieve and put it into the large mixing pan.

STEP THREE - Mix the 6½ pound sample thoroughly with enough water to dampen the soil to [illegible] slightly when squeezed firmly in the hand.

STEP FOUR - Place this material in an air tight container and store it at least 24 hours to insure uniform moisture distribution throughout the sample. The storage period may be reduced or even omitted on soils in which only a small amount of mixing water is added, or on soils which readily absorb moisture.

STEP FIVE - Weigh and record the weight of laboratory compaction cylinder (cylinder only).

STEP SIX - Attach cylinder with collar to base plate.

STEP SEVEN - Place approximately [illegible] pounds of the moist sample into a mixing pan, and place a sufficient amount in the compaction cylinder or mold to yield approximately a one (1) inch compacted layer. During compaction, the mold should rest firmly on a uniform rigid foundation, equivalent to a 200 pound block of concrete.

STEP EIGHT - Place the tamping rod in the guide and compact the material in the mold with 25 blows, uniformly distributed over the area. Use a full drop for each blow.

STEP NINE - Repeat step seven for the second and third layers. The third layer should extend slightly above the top of the cylinder to allow for trimming of the sample.

STEP TEN - Remove collar from the cylinder and carefully trim the excess portion of the compacted material to the exact level of the top of the cylinder.

STEP ELEVEN - Remove cylinder with contained wet sample from the base plate, weigh and record on Illustration 5.

$$\text{Wet density} = \frac{\text{Weight of the wet soil}}{\text{Volume of the soil}}$$

STEP TWELVE - Place the cylinder with contained sample on the floor and test for penetration resistance. This test is made by forcing the penetration resistance needle into the compacted soil at a rate of approximately 1/2 inch per second.

The following precautions are taken when this test is made:

(1) Place the indicator clip against the barrel cap.

(2) The test should be started by grasping the penetrometer barrel and pushing the needle about ½ inch into the compacted specimen. The penetrometer is then held by the handle and the needle is pushed into the specimen an additional 2½ inches at a rate of ½ inch per second.

(3) Occasionally, the compacted specimen contains hard sections or layers and the penetration needle will not penetrate at a uniform rate. The force applied to the penetrometer builds up until the needle "breaks through". When this condition is realized, the reading obtained should be discarded and another penetration resistance test performed. When the needle reaches the hard section, the pressure on the handle should be released and the needle forced through the hard layer by grasping the penetrometer barrel. Then the test should be continued by using the penetrometer in the normal manner. When the needle has penetrated the specimen at a uniform rate to a depth of approximately 3 inches, the reading on the plunger is read. The average of three or more readings and the number of the needle is recorded.

STEP THIRTEEN - Remove the compacted soil from the cylinder and take a sample for moisture determination from the center of the specimen and place it in an evaporating pan.

STEP FOURTEEN - Weigh the pan and wet sample. Oven dry the material and weigh the pan and dry sample. Weigh the pan. Record these weights on Illustration 5.

STEP FIFTEEN - Compute the moisture content expressed in percentage of dry weight, and the dry density in lbs. per cubic foot.

$$\text{Moisture content} = \frac{\text{Weight of moisture}}{\text{weight of dry soil}} \times 100$$

STEP TEN - Remove collar from the cylinder and carefully trim the excess portion of the compacted material to the exact level of the top of the cylinder.

STEP ELEVEN - Weigh cylinder with compacted wet sample from the base plate, weigh and record on illustration 2.

Wet density = $\frac{\text{Weight of the wet soil}}{\text{Volume of the mold}}$

STEP TWELVE - Place the cylinder with compacted sample on the floor and test for penetration resistance. This test is made by forcing the penetration resistance needle into the compacted soil at a rate of approximately 1/2 inch per second.

The following precautions are taken when this test is made:

(1) Place the container with sample, on level spot.

(2) The test should be started by grasping the penetrometer handle and pushing the needle about ½ inch into the compacted specimen. The penetrometer is then held by the handle and the needle is pushed into the specimen an additional 2½ inches at a rate of ½ inch per second.

(3) Occasionally, the compacted specimen contains many pebbles or layers and the penetration needle will not penetrate at a uniform rate. The force applied to the penetrometer builds up until the needle "breaks through". When this condition is realized, the reading obtained should be discarded and another penetration resistance test performed. When the needle reaches the next section, the pressure on the handle should be released and the needle forced through the next layer by grasping the penetrometer handle. Then the test should be continued by using the penetrometer in the normal manner. When the needle has penetrated the specimen at a uniform rate to a depth of approximately 3 inches, the reading on the plunger is noted. The average of three or more readings and the number of the needle is recorded.

STEP THIRTEEN - Remove the compacted soil from the cylinder and take a sample for moisture determination from the center of the specimen and place it in an evaporating pan.

STEP FOURTEEN - Weigh the pan and wet sample. Dry, dry the material and weigh the pan and dry sample. Using the scale, record these weights on illustration 3.

STEP FIFTEEN - Compute the moisture content expressed in percentage of dry weight, and the dry density in lbs. per cubic foot.

Moisture content = $\frac{\text{Weight of moisture}}{\text{Weight of dry soil}} \times 100$

$$\text{Dry density} = \frac{\text{wet density}}{100 + \text{\% of soil moisture}} \times 100$$

Record on Illustration 5.

STEP SIXTEEN - Repeat Steps 5 through 15 for a minimum of 5 trials with new batches of soil from the 40 pound sample. Increase the moisture content for each trial until the wet density of the sample decreases, even though more than 5 trials are required.

STEP SEVENTEEN - Data from tests are plotted. Dry density and penetration resistance are plotted as ordinate values with percent of moisture plotted as abscissa values for both curves. Illustration 6 is used for plotting these curves.

After plotting the density curve, the peak value and the corresponding moisture content are designated as maximum standard density and optimum moisture, respectively.

7. Application of the Unified Soil Classification System to Small Earth Dam Construction

EXAMPLE ONE - Foundation Investigations

The Unified Soil Classification System is applied in classifying soils removed from borings in foundation investigations for small earth dams.

Each stratum in the soil profile is located as to depth in the profile and thickness of the stratum. The material from each stratum is filed separately and classified according to the procedure given in 5. Visual and Manual Classification. This procedure is followed for each hole drilled. The data is recorded on Illustration 1.

A study of the classified soil data will establish the need for laboratory analysis by a reputable laboratory and criteria for design of structure and foundation preparation. When a question arises on the stability or suitability of foundation material, a representative sample of the soil material in question will be sent to a soils laboratory for analysis. The investigation, soil classification, and soil analysis will be made from one to two years prior to target date of construction.

EXAMPLE TWO - Borrow Area Explorations

Classify the soil material from each boring as described in Example One. After a careful study of the classified soil data, select a representative sample from each soil group and prepare 40 pounds of it for shipment to a soil laboratory for analysis.

Take a like sample of the same size to the field laboratory for analysis. The explorations, soil classification, and soil analysis by a reputable laboratory will be made 1 to 2 years prior to target date to commence construction.

The sample for the field laboratory tests will be tested during the slack work season. The Unified Soil Classification System Procedures outlined in 6. Laboratory Classification of Soils will be used in classifying the sample. These tests include the gradation test for determining the soil group; the compaction test for determining density; and the Atterberg test for determining the liquid limit, plastic limit, and plasticity index. In the test for liquid limit, plot on semilogarithmic graft paper a flow curve, which represents the relationship between water content of the soil sample and the corresponding number of blows. Use the ordinate, which is the arithmetical scale, to represent the water content and the abscissa, which is the logarithmic scale, to represent the number of blows. Refer to Illustration 4.

The water content, expressed as a percentage of the oven dried soil, corresponding to the intersection of the flow curve with the 25-blow abscissa is the liquid limit of the soil sample.

Soils with a plasticity index between 10 and 25 are best adapted for constructing earth embankments. Soils with plasticity index below these limits (primarily silts and fine sands or sands) are naturally pervious by nature and have weak to no cementing qualities. Soils with plasticity index above these limits, (primarily clays) tend to have a high shrinkage factor and are progressively hard to work as the plasticity index increases. Special care is necessary in the placement of these types of soil to obtain the proper density-moisture relationship for maximum stability. The Bureau uses soils with a plasticity index between 10 and 20 for compaction around outlet structures in dams.

The Proctor compaction test, which determines the relationship of moisture to density, is made as described in 6D, STEP TWELVE. With dry density values plotted as ordinates and corresponding water contents as abscissa, plot the point for each test, then draw a smooth curve through each point. The water content corresponding to the peak of the curve is the "optimum" water content. The dry density in pounds per cubic foot corresponding to the "optimum" water content is the Proctor maximum dry density. Compacted earth embankments require a rather rigid control of water content and density for soil material used in the construction.

The question often arises - why make the test at the district level when samples are submitted to the laboratory for analysis? The answer is two-fold. First, the tests are made by the Inspector for earth dam construction. Through the process of making these simple tests, he gets a "feel" of the soil, how it reacts when water is added, and pressure for compaction is applied. With this knowledge, he knows what to expect when the soil is compacted into an embankment at optimum moisture content. He will do a more efficient and effective job in getting the job done in conformance to specifications. An inspector who knows nothing about the engineering properties of the soil with which he is working is more likely to question specification requirements and fail to assure conformance with them.

The second has to do with a change in fill material. This change is most likely detected when during placement of compacted earthfill, a

field density test suddenly shows an increase or decrease in density from previous tests made on compacted fill placed at similar moisture content and similar compactive effort. If such a condition occurs, sufficient check density tests should be made to rule out any errors in the test or lack of compactive effort. After these possibilities have been ruled out, it becomes apparent that there are changes in the borrow material which cause it to react differently under compaction than did the test sample from which the Proctor compaction curve was made. When this occurs, a new compaction curve should be made immediately on a sample of the material then being used. The optimum moisture and Proctor density for the "new" material is thus obtained. If indications show the need for it, make the Atterburg test. Under construction conditions, time does not permit the shipment of 40 lb. soil sample to a laboratory and await a report on its engineering properties. The tests as required must be performed on the job.

8. Field Control of Soils in Compacted Earthfill Construction

Soil is the basic structural material in compacted earthfill construction. Water is an auxiliary material. Compaction is a process of construction. First, the properties and characteristics of the soil material proposed for use in the structure are determined. Second, designs and specifications based on the use of the particular soil encountered are developed. Third, control of materials and processes that will result in the desired final product, a compacted earthfill, is provided. This step may be compared to the control of the mixing and placing of cement, aggregate, and water to result in the desired quality of concrete.

The specifications state the required degree of compaction (normally 95% of standard Proctor Density in BLM detention dam construction) and the method of mixing and compacting the materials. The standard Proctor Compaction curve for the particular soil that is being used gives the standard or yardstick for compaction control. By comparing the actual in-place density of the soil in the fill with the standard compaction curve representative of that soil, the degree of compaction is determined. The field in-place density test determines the dry density and the moisture content of the compacted fill. For control purposes, these values are compared with the laboratory maximum dry density and the optimum moisture content. The inspector makes sufficient fill density checks during construction to make sure that every part of the earthfill meets specification requirements. Determination of the moisture content of the material in the fill is an important part of the density test. It is important that the moisture content of the completed fill be at or near Proctor optimum. Some very plastic clays become "spongy" under heavy earth-placing machinery at optimum moisture content, and because of this, are compacted slightly dry of optimum moisture for best workability. By additional compactive effort, it is possible to compact some soils to maximum Proctor Density at moisture content below optimum. However, tests show that most soils compacted to a given density and below optimum moisture increase in permeability. As the moisture content is decreased, permeability increases rapidly. For best results, soils with a low plasticity index are compacted with moisture content at or slightly above optimum.

Also, the maximum Proctor density can be obtained with the minimum compactive effort when the moisture content of the soil is near optimum.

A. FIELD DENSITY TEST

This test is employed to obtain the moisture content and the in-place density of the soil in the fill, and to determine the percent of standard Proctor density by comparison with the proper Proctor compaction curve. Three methods are presently employed by the BLM for determining the volume of hole from which the test sample is taken: (1) The sand cone method, (2) the Volumeasure method, (3) the drive cylinder method. The procedure for making this test, using the sand cone method for determining the volume of the test hole, is outlined in the following paragraphs. See list of equipment.

STEP ONE - Calibrate density sand

Weigh a container of known volume (either a 1/10 cubic foot standard sand bucket or the 1/20 cubic foot standard compaction mold is satisfactory.). Fill the measure with clean, dry screened sand, selected for use in making the density tests. Use the sand cone device for pouring the sand into the measure. In pouring the sand into the measure, duplicate the procedure for pouring sand into the actual test hole as closely as possible. When the measure is full, carefully level the sand even with the top, using a straight steel edge. Care must be exercised to avoid jarring the measure or disturbing the sand during the filling and leveling procedure. Weigh the sand and measure, and determine the weight of the sand. The weight of the sand in pounds per cubic foot is the weight of the sand in pounds divided by the volume of the measure in cubic feet. Make several trials until the results of the calibration are consistent. Record the calibrated weight of the density sand for future use.

When using the sand cone device in making density tests, the weight of sand required to fill the cone and template must be determined. Fill the cone device with sand and weigh. Place the template on a smooth flat surface. Place the cone in position on the template and open the valve. After the cone is filled, close the valve and weigh the cone device and sand remaining in it. Make several trials and obtain average weight of sand required to fill template and cone.

STEP TWO - Obtain the density sample

Weigh the sand cone device filled with previously calibrated density sand. Select a site on the fill or embankment for making the test, taking care that the visually apparent moisture content and degree of compaction is representative of the entire fill area that the test represents. Remove all loose soil from an area 18 to 24 inches square and level to a firm, smooth surface, being careful not to step on or near the spot where the test hole is dug. Place the template snugly and firmly on the test area.

With the template in place, dig a hole slightly smaller than the hole in the template. This may be done with adaptable hand tools. The hole should have a volume in excess of 1/20 cubic foot. Using a template with a 4 inch diameter hole, an excavation approximately 8 inches deep

would be required. The hole should be smooth and undeformed. Movement of heavy equipment in the immediate area is not permitted while the sample is taken.

Immediately place the material taken from the hole in an airtight container for subsequent weighing in the field laboratory. Precautionary measures shall be taken to minimize the loss of moisture from the soil from the time it is taken from the hole until it is weighed, and the sample for moisture determination is taken from it and weighed.

Determine the volume of the hole by carefully filling it with the calibrated density sand, using the sand cone device. Place the cone on the template, open the valve, and allow the sand to fill the hole and cone. Close the valve. If the sand is to be reclaimed, remove it from the hole and place in a separate container.

All reclaimed sand must be rescreened and recalibrated before being reused.

For fill containing large gravel sized material and cobbles, a larger hole or test pit will be necessary to determine the density of the material. The volume of the excavation is determined either by accurate measurements or by the use of a coarse density sand (No. 4 to No. 8 sieve particle sizes).

STEP THREE - Determine the wet density

Weigh the wet soil removed from the test hole to the nearest 0.01 pound.

Weigh the sand cone device with the remaining sand, and compute the weight of the sand required to fill the test hole to the nearest .01 pound. This will be the weight of the sand cone device and sand before filling the hole, minus the weight of the sand cone device and sand after filling the hole, minus the weight of sand in the cone and template.

Compute the volume of the hole. This will be the weight of the sand required to fill the test hole divided by the weight of the density sand in pounds per cubic foot. The wet density in pounds per cubic foot is the weight of the wet soil from the hole divided by the volume of the hole.

Use Illustration 7 for recording date and making computations.

STEP FOUR - Determine the dry density

To determine dry density, the moisture content of the sample must be obtained. The moisture content is expressed in percent of the oven dry weight of the soil. Weigh a suitable sized drying pan or dish. Place a sample of the wet soil in the pan and weigh the dish and sample. The weight should be accurate to 0.1 gram. The size of sample selected depends on the quantity required for good representation and on the accuracy of weighing. About 200 grams is adequate for minus No. 4 sized material.

Place the sample material in a drying oven maintained at 110° C (230° F) temperature. The drying period shall be sufficient to permit drying of the soil to constant weight. The time required may vary from a few hours for sandy soils to several days for "fat" clays. Sixteen (16) hours or overnight is the usual time employed.

After it has dried to constant weight, remove the sample from the oven, place a tight lid on the container, and cool to room temperature. Determine the dry weight of the cooled soil.

$$\% \text{ Moisture} = \frac{\text{weight wet soil and pan - weight dry soil and pan}}{\text{weight dry soil}} \times 100$$

$$\text{Dry density} = \frac{\text{wet density}}{100 + \% \text{ moisture}} \times 100$$

STEP FIVE - Determine percent of standard Proctor compaction

$$\% \text{ Compaction} = \frac{\text{dry density}}{\text{Proctor maximum dry density}} \times 100$$

The Proctor maximum dry density is obtained from the Proctor compaction curve previously prepared in accordance with Chapter 5.2B3.

Use Illustration 7 for recording data and making computations.

STEP SIX - Proctor compaction check at field moisture content

After the wet density has been determined for the soil sample excavated from the compacted fill and the 200 gram sample removed for drying, prepare the remainder for making a Proctor compaction test. The Proctor compaction mold will be filled and weighed in the manner described under Chapter 5.2B. The Proctor dry density of the material compacted with the same moisture content as the material in the compacted fill is thus obtained. Plot a point on the standard Proctor curve, using the Proctor dry density thus obtained as the ordinate and the moisture content as the abscissa, Illustration 6. The point should fall reasonably close to the standard Proctor compaction curve already plotted. If it doesn't, there is good indication that the fill material has changed, and that the standard curve is not representative of the fill material currently being used. Such a result would indicate the need to prepare a new standard curve or to examine the conditions in the borrow pit to determine the cause of the apparent change in material.

This sixth step need not be taken in connection with every density test, but should be made occasionally as a check on the density test, and whenever there is reason to suspect a change in the borrow pit material.

B. VARIATIONS IN THE PROCEDURE FOR MAKING THE FIELD DENSITY TEST

1. The Volumeasure is an acceptable alternate to the sand cone device for determining the volume of the test hold. Its use is not recommended in cases where the test hole cannot be excavated with relatively smooth side walls. This device entails the measurement of the volume of water

required to fill the hole. A flexible rubber "balloon" inflated to conform to the shape of the hole contains the water.

The 1/20 cubic foot size volumeasure is the smallest size practical in BLM work. In order to minimize errors in measuring and weighing, and to assure a representative sample, it is important to excavate the hole as nearly as possible to the maximum size capable of being measured by the volumeter. Except for the use of the volumeter instead of sand cone to measure volume of hole, the procedure for making the field density test is the same as described in 8A.

2. The Drive Cylinder provides a convenient and rapid means of obtaining an in-place density sample. While this method should not replace the standard sand cone method, it does have application for use in obtaining samples in hard-to-get-to places such as under and around pipes, and other structures, and where rapid test results are a necessity. To use this method, a sample is taken by driving a cylinder of known volume directly into the material. To simplify computations, the cylinders are made with a volume of exactly 62.4 cubic centimeters so that the weight of the material in the cylinder in grams is equal to the weight of a cubic foot of the material in pounds, which is the wet density of the material. The sample is then dried to obtain the dry density.

3. The Ignition Method provides a very rapid and simple means of drying samples for moisture determination. For compaction control during construction, it is necessary for the inspectors to make rapid density determinations so that timely remedial action can be taken if the required density is not being obtained in the fill being placed. The oven drying process for moisture content requires approximately sixteen (16) hours. Drying by the ignition process can be effected in minutes and should give results accurate to within one percentage point of moisture. The ignition method can be used to supplement the oven drying method, thus tentative results of density test can be obtained immediately and verified later after the oven drying process is completed.

The following procedure is used for obtaining moisture content by the ignition method:

> Weigh a 50 to 60 gram sample of the moist soil. Place this soil in a flat bottom porcelain dish of known weight. Add 30 to 40 cubic centimeters of denatured alcohol. Stir the mixture thoroughly with a porcelain spatula for 2 or 3 minutes and ignite.
>
> After complete burning, again add 30 or 40 cubic centimeters of alcohol and repeat the process. Reweigh the sample to determine the dry weight. The moisture content is computed in the usual manner. It may be necessary to subject clayey soils of high plasticity to three (3) ignition treatments to obtain accurate results.

C. USE OF PROCTOR NEEDLE

The Proctor penetration-resistance needle test is used in conjunction with the in-place density test in field control as an indicator of the moisture-density relationship. A soil when compacted dry offers a very high resistance to penetration, but as water is added, the soil particles become better lubricated and consequently offer less resistance to penetration. With a constant degree of compaction, the density will vary with changes in moisture content, and as the density increases, the penetration resistance will also increase. Thus, with a known density condition of the soil, the Proctor needle reading values give an <u>indication</u> of the moisture condition. For example, the density is known to be near 100% of Proctor maximum. The standard penetration resistance curve for that particular soil shows a resistance 900 p.s.i. at optimum moisture. Any Proctor needle reading greater or less than 900 p.s.i. indicates that the soil contains respectively less or more than optimum moisture content.

Conversely, with a known moisture content of the soil, the Proctor needle reading values give an indication of the density. For example, the moisture content is known to be 14%. The standard penetration resistance curve for that particular soil shows a resistance of 1000 p.s.i. indicating inadequate compaction.

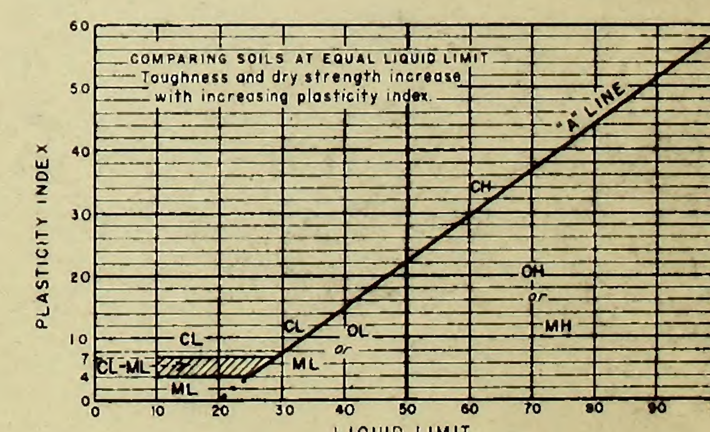
The inspector makes spot checks of the embankment material with the Proctor needle in addition to the standard density tests. With practice and by constantly comparing results with actual field density tests, he becomes quite proficient at detecting inadequate compaction or inadequate moisture content by this means.

UNIFIED SOIL CLASSIFICATION

INCLUDING IDENTIFICATION AND DESCRIPTION

FIELD IDENTIFICATION PROCEDURES (Excluding particles larger than 3 inches and basing fractions on estimated weights)				GROUP SYMBOLS [1]	TYPICAL NAMES	INFORMATION REQUIRED FOR DESCRIBING SOILS	LABORATORY CLASSIFICATION CRITERIA	
COARSE GRAINED SOILS More than half of material is larger than No. 200 sieve size [2] (The No. 200 sieve size is about the smallest particle visible to the naked eye)	GRAVELS More than half of coarse fraction is larger than No. 4 sieve size (For visual classifications, the ¼" size may be used as equivalent to the No. 4 sieve size.)	CLEAN GRAVELS (Little or no fines)	Wide range in grain size and substantial amounts of all intermediate particle sizes.	GW	Well graded gravels, gravel-sand mixtures, little or no fines.	Give typical name; indicate approximate percentages of sand and gravel, max. size; angularity, surface condition, and hardness of the coarse grains; local or geologic name and other pertinent descriptive information; and symbol in parentheses.	Use grain size curve in identifying the fractions as given under field identification. Determine percentages of gravel and sand from grain size curve. Depending on percentage of fines (fraction smaller than No. 200 sieve size) coarse grained soils are classified as follows: Less than 5% GW, GP, SW, SP. More than 12% GM, GC, SM, SC. 5% to 12% Borderline cases requiring use of dual symbols.	$C_u = \frac{D_{60}}{D_{10}}$ Greater than 4; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between one and 3
			Predominantly one size or a range of sizes with some intermediate sizes missing.	GP	Poorly graded gravels, gravel-sand mixtures, little or no fines.			Not meeting all gradation requirements for GW
		GRAVELS WITH FINES (Appreciable amount of fines)	Non-plastic fines (for identification procedures see ML below).	GM	Silty gravels, poorly graded gravel-sand-silt mixtures.			Atterberg limits below "A" line, or PI less than 4. Above "A" line with PI between 4 and 7 are borderline cases requiring use of dual symbols.
			Plastic fines (for identification procedures see CL below).	GC	Clayey gravels, poorly graded gravel-sand-clay mixtures.	For undisturbed soils add information on stratification, degree of compactness, cementation, moisture conditions and drainage characteristics.		Atterberg limits above "A" line with PI greater than 7
	SANDS More than half of coarse fraction is smaller than No. 4 sieve size	CLEAN SANDS (Little or no fines)	Wide range in grain sizes and substantial amounts of all intermediate particle sizes.	SW	Well graded sands, gravelly sands, little or no fines.			$C_u = \frac{D_{60}}{D_{10}}$ Greater than 6; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between one and 3
			Predominantly one size or a range of sizes with some intermediate sizes missing.	SP	Poorly graded sands, gravelly sands, little or no fines.	EXAMPLE:- Silty sand, gravelly; about 20% hard, angular gravel particles ½-in. maximum size; rounded and subangular sand grains coarse to fine; about 15% non-plastic fines with low dry strength; well compacted and moist in place; alluvial sand; (SM)		Not meeting all gradation requirements for SW
		SANDS WITH FINES (Appreciable amount of fines)	Non-plastic fines (for identification procedures see ML below).	SM	Silty sands, poorly graded sand-silt mixtures.			Atterberg limits below "A" line or PI less than 4. Above "A" line with PI between 4 and 7 are borderline cases requiring use of dual symbols.
			Plastic fines (for identification procedures see CL below).	SC	Clayey sands, poorly graded sand-clay mixtures.			Atterberg limits above "A" line with PI greater than 7

IDENTIFICATION PROCEDURES ON FRACTION SMALLER THAN No. 40 SIEVE SIZE		DRY STRENGTH (CRUSHING CHARACTERISTICS)	DILATANCY (REACTION TO SHAKING)	TOUGHNESS (CONSISTENCY NEAR PLASTIC LIMIT)	GROUP SYMBOLS	TYPICAL NAMES	INFORMATION REQUIRED FOR DESCRIBING SOILS
FINE GRAINED SOILS More than half of material is smaller than No. 200 sieve size.	SILTS AND CLAYS Liquid limit less than 50	None to slight	Quick to slow	None	ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands with slight plasticity.	Give typical name; indicate degree and character of plasticity, amount and maximum size of coarse grains; color in wet condition, odor if any, local or geologic name, and other pertinent descriptive information; and symbol in parentheses.
		Medium to high	None to very slow	Medium	CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays.	
		Slight to medium	Slow	Slight	OL	Organic silts and organic silt-clays of low plasticity.	For undisturbed soils add information on structure, stratification, consistency in undisturbed and remolded states, moisture and drainage conditions.
	SILTS AND CLAYS Liquid limit greater than 50	Slight to medium	Slow to none	Slight to medium	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts.	
		High to very high	None	High	CH	Inorganic clays of high plasticity, fat clays.	EXAMPLE:- Clayey silt, brown; slightly plastic; small percentage of fine sand; numerous vertical root holes; firm and dry in place; loess; (ML)
		Medium to high	None to very slow	Slight to medium	OH	Organic clays of medium to high plasticity.	
HIGHLY ORGANIC SOILS		Readily identified by color, odor, spongy feel and frequently by fibrous texture.			Pt	Peat and other highly organic soils.	



PLASTICITY CHART
FOR LABORATORY CLASSIFICATION OF FINE GRAINED SOILS

[1] Boundary classifications - Soils possessing characteristics of two groups are designated by combinations of group symbols. For example GW-GC, well graded gravel-sand mixture with clay binder.
[2] All sieve sizes on this chart are U.S. standard.

Figure 1.

Illustration 1

VISUAL CLASSIFICATION OF SOIL SAMPLE

Project ____________________ Classifier ____________________

Hole Location ____________________ Date ____________________

Hole No. ____________________

IDENTIFICATION										DESCRIPTIVE DATA (Fine Grain Sample)																	
	Sample			Coarse Grain				Fine Grain		Plasticity Test Reaction			Shake Test Reaction			Dry Strength Test			Acid Test			Shine Test		Organic Content			
Depth in Feet	Sample No.	Coarse Grain	Fine Grain	% Larger 3 ins.	Gravel (% plus #4)	Sand (% #4 - #200)	Grain Shape	Silt & Clay (% minus #200)	Group Symbol	High	Medium	Low	Quick	Slow	None	High	Moderate	Slight	Strong	Slight	None	Shiny	Dull	High	Small	Trace	None

GRADATION BY SIEVE ANALYSIS

Project ______________________________ Date ____________________

Sample No. from which sample taken ____________________

Wt. of Dry Sample _____________gms.

Washing loss (if prewashed) + Wt. passing No. 200 sieve= -No. 200 (Total)*

Wt. of Prewashed Sample _____________gms.

Wt. of dry sample after washing _________gms.

Washing loss (Passing No. 200 sieve) _____________gms.

Screen or Sieve	Weight of Soil & Sieve	Weight of Sieve	Weight Retained	Weight Passing	% of Total Passing
3"					
1"					
½"					
No. 4					
No. 8					
No. 16					
No. 30					
No. 50					
No. 100					
No. 200					
Pan				XXXXXXXXXXXX	XXXXXXXXXXXXXXX
No. 200 (Total)	XXXXXXXXXXX	XXXXXXXXXXX	XXXXXXXXXX		

REMARKS:

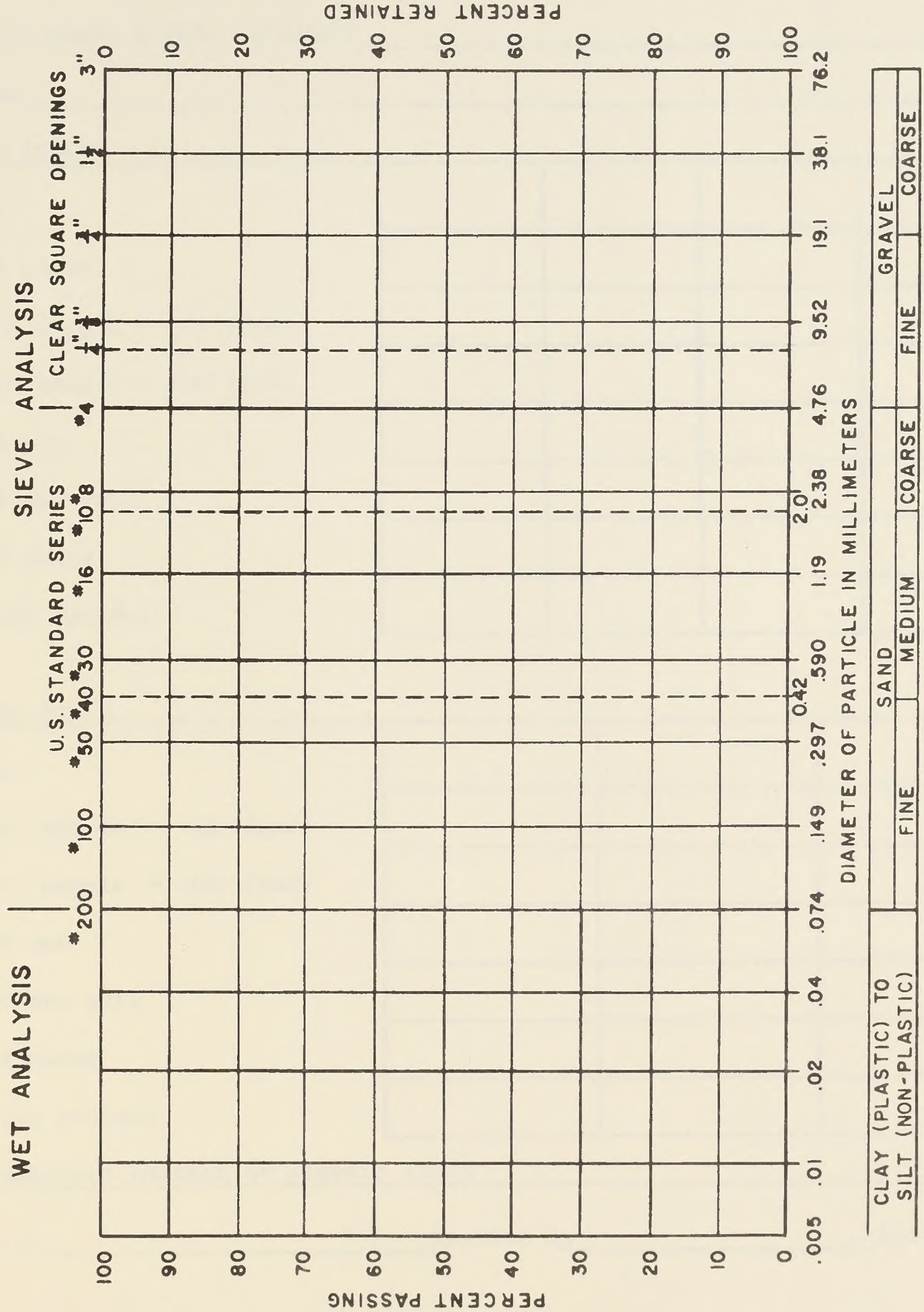
By ____________________

Illustration 2A

O.N.K. 4/59

Project ____________ Location ____________

Sample No. ____________



Gravel ______ %

Sand ______ %

Silt to Clay ______ %

Tested by ____________ Date ______

Checked by ____________ Date ______

ATTERBERG LIMITS

Sample No.____________________ Project ____________________

Location where sample obtained______________________________

Remarks____

Liquid limit

Can No.				
No. of blows				
Wt. wet sample + can (gms)				
Wt. dry sample + can (gms)				
Wt. of can				
Wt. of dry soil				
Wt. of water				
Moisture content				

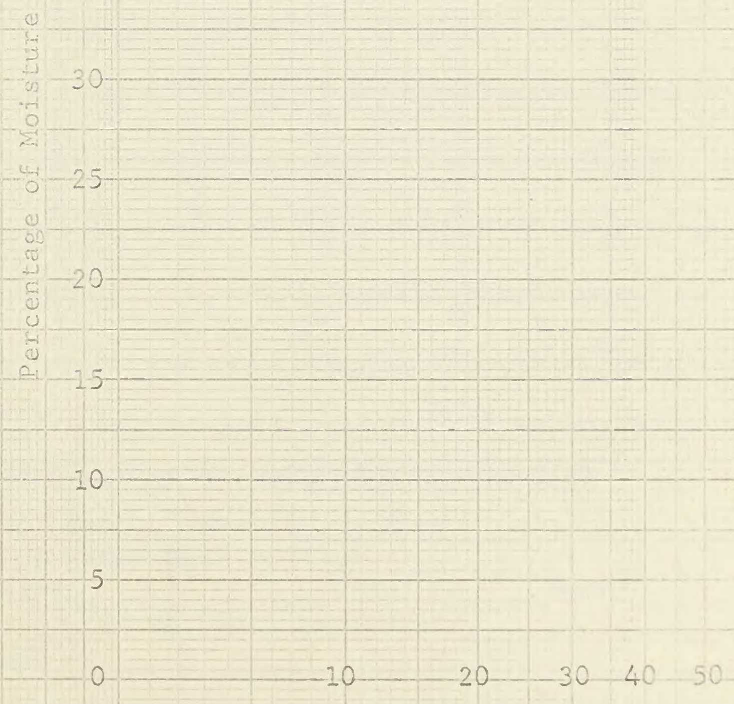
Plastic limit

Can No.			
Wt. wet sample + can (gms)			
Wt. dry sample + can (gms)			
Wt. of can			
Wt. of dry soil			
Wt. of water			
Moisture content			
Ave. moisture content or plastic limit			

Comp. by____________________ Checked by____________________ Date__________

FLOW CURVE

Illustration 4



SOIL COMPACTION TESTS FOR OPTIMUM MOISTURE CONTENT

Sample No.__________ Project ______________________________ Feature______________

Compacted by_________________________ Recorded by_______________ Date_______________

Degree of compaction_________________ Volume of Cylinder_______________________________

Location of Sample Obtained____

____

Test No.	1	2	3	4	5	6	7	8
Density Determinations								
Water Added - C.C.								
Wt. Cyl. & Wet Earth - lb.								
Wt. of Cylinder - lb.								
Wt. of Wet Earth - lb.								
Wet Density lb./cu. ft.								
Moisture Determinations								
Dish No.								
Wt. Dish & Wet Soil - g.								
Wt. Dish & Dry Soil - g.								
Weight of Dish - g.								
Weight of Water - g.								
Weight of Dry Soil - g.								
Moist. Cont. % Dry Wt.								
Dry Density lb./cu. ft.								

Computed by __________________ Checked by ______________________ Date _______________

QUESTIONS TO ANSWER FROM OBSERVATIONS BY OPERATORS DURING TEST

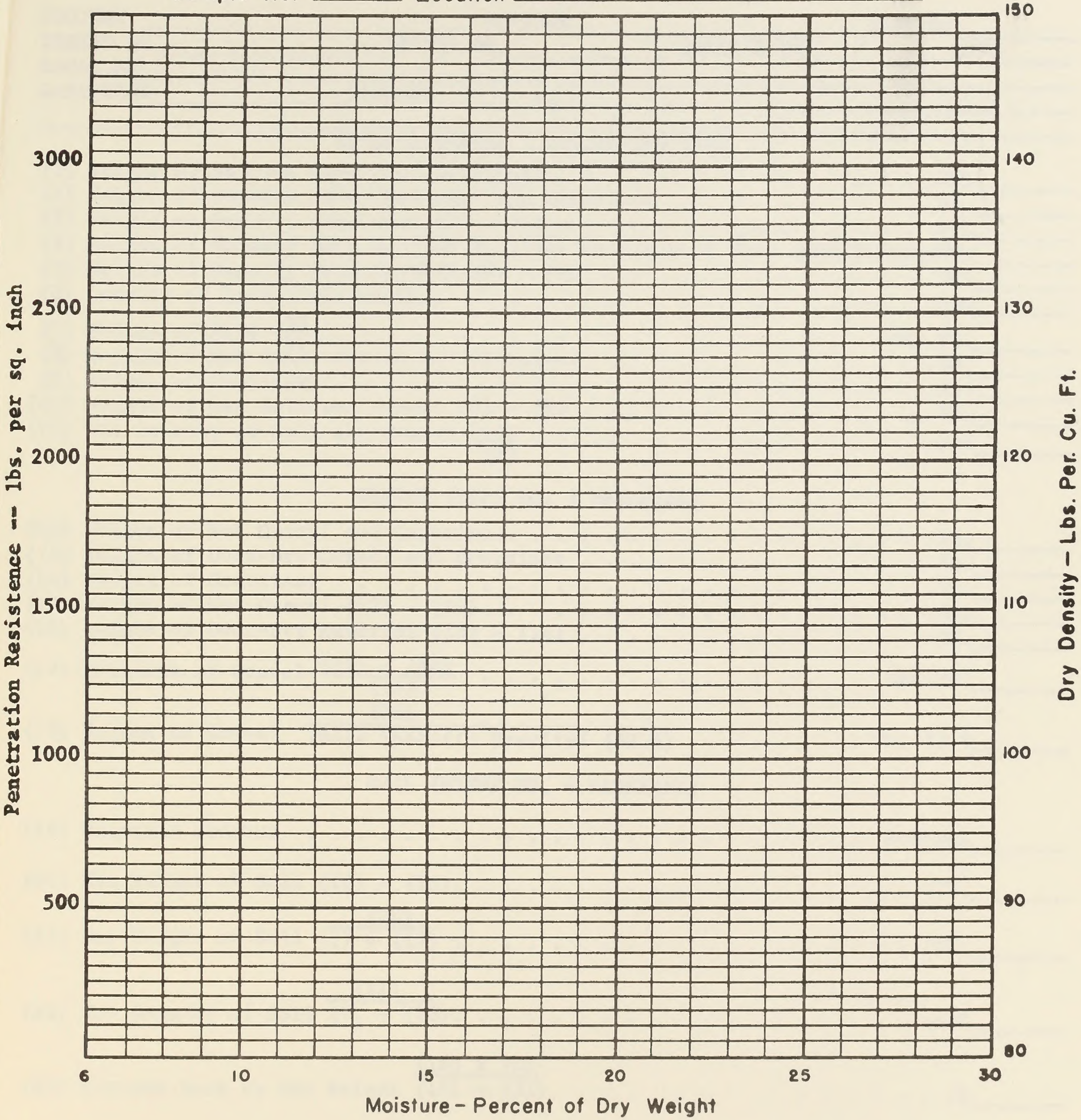
1. How fast does sample absorb water? Fast____Medium_____Slow________________
2. Is difficulty encountered in mixing water with soil?____________________
3. At what test Nos. is sample crumbly?________________Firm?_________Soft?________
4. Was bleeding noticed during test?_____If so, what test Nos.?________________
5. At what test Nos. is sample spongy?____
6. Other comments____

____

COMPACTION TEST CURVES

Project ______________________________

Sample No. ________ Location ______________________________



Atterberg Limits	Soil Properties
LIQUID LIMIT ______________	SPECIFIC GRAVITY ______________
PLASTIC LIMIT ______________	SOIL CLASSIFICATION ______________
PLASTICITY INDEX ______________	% LARGER THAN TESTED ______________
	MAX. STD. DRY DENSITY ________ LBS./CU. FT.
	OPTIMUM MOISTURE ________ %

Tested by ______________ Date ____ Checked by ______________ Date ____

R.L.J. 4/58

EARTH TESTING
IN-PLACE DENSITY TEST OF SOILS
(FOR SOILS CONTAINING GRAVEL PARTICLES)

PROJECT ____________ FEATURE ____________ TEST NO. ________
TESTED BY ____________ COMPUTED BY ____________ CHECKED BY ____________ DATE ________
LOCATION ____
ELEVATION ____________ REMARKS ____________________________

TOTAL MATERIAL - GRAVEL AND SOIL

(1) Weight of Density Sand and Container. . . . . .lb. ________
(2) Weight of Density Sand (Residue) and Container. . . . . .lb. ________
(3) Weight of Density Sand Used (1) - (2) . . . . .lb. ________
(4) Weight of Density Sand to Fill Template and Cone if Used (Calibration) lb. ________
(5) Weight of Density Sand in Hole (3) - (4). . . . . .lb. ________
(6) Density of Sand (Calibration) . . . . .pcf ________
(7) Volume of Hole $\frac{(5)}{(6)}$. . . . . .cu. ft. ________
(8) Weight of Wet Soil, Gravel and Container. . . . . .lb. ________
(9) Weight of Container . . . . .lb. ________
(10) Weight of Wet Soil and Gravel (8) - (9) . . . . .lb. ________
(11) Wet Density of Soil and Gravel $\frac{(10)}{(7)}$ . . . . .pcf ________

GRAVEL (PLUS NO. 4 MATERIAL)

(12) Weight of Wet Gravel and Container. . . . . .lb. ________
(13) Weight of Oven-Dry Gravel and Container . . . . .lb. ________
(14) Weight of Container . . . . .lb. ________
(15) Weight of Wet Gravel (12) - (14). .lb. ________
(16) Weight of Oven-Dry Material (13) - (14) . . . . .lb. ________
(17) Moisture of Gravel $\frac{(15) - (16)}{(16)}$ . . . . decimal ________
(18) Volume of Gravel $\frac{(16)}{(\text{Bulk Specific Gravity})\ (62.4)}$ . . . . cu. ft.* ________

SOIL (MINUS NO. 4 MATERIAL)

(19) Moisture Content . . . . decimal ________
(20) Wet Weight of Soil (10) - (15). . . . . .lb. ________
(21) Dry Weight of Soil $\frac{(20)}{(1) + (19)}$ .lb. ________
(22) Dry Density of Soil $\frac{(21)}{(7) - (18)}$. . . . . .pcf ________
(23) Percent Rock by Dry Weight $\frac{(16) \times 100}{(16) + (21)}$ . . . .% ________

*May be determined directly by the Displaced Method if the quantity of gravel does not exceed capacity of the siphon can.

HYDROLOGY

INDEX

HYDROLOGY

INTRODUCTION

That phase of water movement over the ground surface and through the soil mantel of the earth from the time it encounters the earth's surface within a given drainage basin as rain, hail, or snow is the subject of this chapter. We refer to this movement as watershed hydrology. It is complex because of the variation in the natural phenomena which causes precipitation and the natural and man-made influences which determine the relationship of surface flow to water movement into and through the soil. This treatise is not a scientific analysis for the study of these phenomena and influences. Rather, it sets forth methods for determining the relationship of surface runoff to precipitation for any given watershed.

The methods are specifically oriented for use in determining runoff within and from small watersheds that are located within the range lands of the Western States. They are taken from Engineering Handbook, Section 4, Hydrology, Soil Conservation Service.

1 Preparatory Work

Before anyone is prepared to begin the process of determining watershed hydrology it is important that he become acquainted with data requirements, where and how to get the data, how to group, analyze and summarize it, and how to apply it. Aids have been developed for use in collecting and analyzing hydrologic data. Some of these are listed and techniques explained.

To determine watershed hydrology is to find out how much water reached the ground surface, at what rate it falls and what happened to it after making contact with the ground surface. Once this contact is made observations and experimental study show that soil and vegetation influence the course of movement--over the surface, into and through the soil, and return to the atmosphere. We are primarily concerned with the two movements first mentioned. We are interested in surface flows because of damages it may do and structural designs required to manage it. Since plant growth depends on availability of soil water and underground flows and aquifers are maintained by water percolating through the soil, we are concerned with the water that enters the soil.

Experimental work shows that the type and density of the plant cover and soil types influence the rate and amount of surface runoff that occurs from a storm. There is a relationship between runoff and precipitation. Therefore, that phase of watershed hydrology concerned with surface flows is the process of (1) measuring and computing the precipitation depth, the rate at which it falls, and the storm duration, (2) determining the relationship of runoff to precipitation. Rainfall depths, storm duration,

and stream flow measurements are available but limited. Runoff precipitation relationships have been determine for a few watersheds. Through a process of hydrologically grouping soils and cover types the application of results measured to show the relationship of runoff to precipitation on a few experimental watersheds may be applied within a reasonable degree of accuracy to others. The grouping is referred to as the soil-cover complex.

Field surveys are required to get soil and cover information for hydrologically grouping the soil and vegetative types. Range surveys have been made for large blocks of the range lands. Few soil surveys have been made on these lands but will likely increase in the future. Never undertake a field survey until you have checked records and all possible sources for data previously taken and recorded by individuals or parties. Summarize the information on vegetation and soil as outlined in section 3 and 4. Field surveys will be made to get whatever information is lacking for making the groupings.

Another source of hydrologic data obtainable from field observations and measurements is peak runoff. The main channel and primary tributaries are divided into sections. Each section has a definite set of channel characteristics and a slope which can be considered uniform. High water marks are located in each section. Cross-section survey is made at the point of high water marks and the slope of the channel through the point for a distance of several hundred feet is determined. The degree of active erosion, channel condition, and deposition will reflect a high or low precipitation runoff relationship. These measurements are taken as outlined in section 6.

2 Climatological Data

Before any attempt is made to determine precipitation, runoff and peak flows from a given community watershed, climatological data for the watershed will be compiled. The two sources for this information are records of measurement and observations of field conditions and indicators.

The Weather Bureau Station in each State collects and maintains records on precipitation, storm types, temperatures, etc. A representative if the State office should make personal contact with the State Weather Station and discuss with them storm movements, rainfall intensities, and other hydrological problems which would be helpful in determining precipitation and the relationship of runoff to precipitation. He will at the same time request that each district, as well as the State office, be put on the mailing list to receive climatological data applicable to the area within the district.

The U. S. Geological Survey collects and maintains records on stream flow. In some drainage basins they have computed precipitation and runoff relationships and water yield in terms of acre-feet per section. It should be the responsibility of the State office to obtain these and any other data which can be used in computing watershed hydrology within the State. The Soil Conservation Service, Agricultural Research Service, and State Highway Departments are also sources of these data.

There are indicators in every drainage basin which gives clues to precipitation and the relationship of precipitation to runoff. Indicators to look

for are types of vegetation, by comparison is the vegetation in size and condition normal, above normal, or abnormal, does it indicate above, below, or normal precipitation cycle, concentration of litter by overland movement of water, gully erosion, high water marks along gully and stream channels, and an estimate of the date of the major flow based on high water marks.

3 Hydrological Cover Condition

The vegetative cover is typed according to range survey procedure for the primary types. The hydrological grouping is the breaking of each type into conditions which reflect the comparative effect of type conditions on runoff. The adjectives good, fair, and poor designate the hydrologic condition class. The standard Bureau procedure for determining the condition class of a vegetative type is basic to making the hydrologic cover condition class. A fair range condition class may or may not reflect a fair hydrologic condition class. It must be kept in mind that the hydrologic condition class reflects the comparative effect a cover type in its present condition has on runoff. The Deming Two-Phase method for estimating range condition classes takes into consideration runoff and should indicate the hydrologic condition class. Field checks are required in estimating hydrologic condition classes. Date Sheet - Hydraulic Cover Condition and Soil Group, Illustration 1, is used for recording data.

The types are plotted on a map and each type is subdivided (when two or more conditions are present) into hydrologic cover conditions. Compute the area in each condition class by use of a planimeter.

4 Hydrologic Soil Groups

The soils in the watershed are grouped into four hydrologic groups. This grouping is made on the basis of the comparative rate at which water enters and moves through the soil. They are designated as Group A, B, C, and D. On a comparative basis water enters and moves throughout Group A very rapidly, Group B rapid to moderate through the effective profile, Group C moderate to slow through the effective profile, and Group D very slow through the effective profile. A further description of this profile is:

Group A is usually made up of deep sands. The silt and clay content of the sands is insufficient to restrict the intake and movement of water. This group has the lowest potential runoff.

Group B is made up of deep sandy soils (sometimes referred to as sandy loams). This group may contain silts and clays but they do not reduce intake and movement of water to a range below a moderate rate. Stratification in the profile composed of sands, gravel, and loams are placed in this group where the overall rate of intake and movement in the effective profile is restricted to the B rating. The potential runoff from this group is below average.

Group C is generally made up of deep clay loam soils. This group contains sufficient clay and silt to restrict intake and movement of

water through the soil to a range from moderate to slow. Also included are stratified soils with inhibiting layers in the effective profile which control movement within Group C rating. The potential runoff for this group is above average.

Group D is generally made up of the heavier clay soils and soils containing clay with high expanding qualities when wet. Stratified soils with one or more layers in the effective profile that restrict water intake and/or movement through the soil to the Group D rate are included. This group has the highest potential runoff.

Outline the soil groups on a map and compute area by use of a planimeter or grid method. Use Data Sheet - Hydraulic Cover Condition and Soil Groups, Illustration 1, for recording the soil groups.

5 Soil-Cover Complex Numbers

A reliable estimate of the relationship of runoff to precipitation is made possible through experimental watershed studies, increased and improved measurements of precipitation and stream gaging, and a closer working relationship among and between hydrologists and meteorologists in various agencies. Estimates will become more accurate as additional and more intense measurements are made in an expanded system of studies and analysis.

As a result of work in this field an equation for computing hydrologic soil-cover complex numbers has been developed.

$$Q = \frac{(P-0.2S)^2}{P + 0.28S}$$

Q = Direct runoff in inches

P = Storm rainfall in inches

S = Maximum potential difference between P and Q in inches at time of storm's beginning.

It expresses a relation between runoff and precipitation for an average in a given soil-cover complex condition. Having established a number for a given hydrologic situation, runoff is computed for precipitation in inches for depth beginning with 0 and increasing consecutively by 1 inch until the depth has reached the maximum expected precipitation. By plotting the precipitation depth in inches along the abscissa and the runoff by depth in inches along the ordinate the points are connected, forming a curve for the given soil-cover complex number. This is the soil-cover complex curve for a given hydrologic situation or soil-cover complex curve number. On Figure 1 are plotted the soil-cover complex curve numbers from 20 through 100.

The soil-cover complex numbers have been computed for five vegetative types found on the Western rangelands. They are given in Table 1. This table is

arranged so that the soil-cover complex number for any combination of established hydrologic cover conditions and hydrologic soil groups is easily selected.

6 Channel Surveys

The first step in this survey is to observe and study the main channel and primary tributaries. Following this, subdivide the watershed into sections. A section has for runoff determination purposes similar channel characteristics and a relatively uniform slope. Locate a point within the lower third of each section with typical channel and slope characteristics. At each point try to reconstruct the history of flow. High water marks and channel conditions will aid in this analysis.

A differential level survey is made at selected points within each stream section to make the required measurements for computing the cross-sectional area of the channel and determine channel gradient through the point. Points indicating high flows are identified in the field notes.

7 Preliminary Estimates of Peak Flows

Work Sheet Illustration No. 3 contains stream flow data obtained by field observations and measurements. By the use of the Manning formula compute the peak flow at the designated point for each channel section on basis of high water mark.

$$V = 1.486 R^{2/3} S^{\frac{1}{2}}$$

V = velocity - rate of flow per second

* n = coefficient of friction

R = hydraulic radius (cross sectional area of channel divided by the wetted perimeter). The wetted perimeter is the distance down one side, across the bottom and up the other side of a conduit or channel cross sectionally with which the water makes contact while flowing at a given depth.

S = slope in feet per foot

Peak flow (q) = Cross sectional area (A) x velocity (V)
q = A x V With units in cubic feet per second (c.f.s.)

8 Time of Concentration

Time of concentration is the time it takes for runoff originating in the most upper reach of the watershed to reach a given point on the channel. Several points may have been established along the channel for which the time of

* The "n" for channels through range country will generally vary between .03 to .05. A study of channel conditions should give the observer sufficient information to place the channel resistance to flow in the lower, medium or high resistant catagory. A systematic analysis of this type plus experience will provide the basis for selecting "n".

concentration will be required. In this case it will be computed from the upper reach to the first point, first point to second point, second point to third point, etc. The time of concentration at the last point will be the sum of the time periods to the points. Time of concentration (Tc) between any two points is computed by the following formula:

$$Tc = \frac{L}{3600\ V}$$

Tc = time in hours

L = length between the two points in feet

3600 is number seconds per hr.

V = velocity - rate of travel in feet per second

The velocity computed from field data on stream flow (Survey notes) for each stream section is used to compute time of concentration.

9 Isohyetal Map

Lines can be drawn on a map to represent equal precipitation depth in inches. These lines are called isohyets. A map containing isohyets or lines which show equal precipitation for a given area is an isohyetal map. Isohyets are to rainfall depth as contours are to elevations.

Isohyetal maps for a 6-hour storm with frequencies of 10, 25, 50, and 100 years are given in the appendix. These should be used in estimating rainfall in inches for a given storm frequency in a given watershed. State office personnel may make the map more detailed to increase the accuracy of estimates by drawing more isohyets provided it is done with the concurrence of the Weather Bureau.

10 Water Yield From a Storm of a Given or Estimated Rainfall Depth

To determine water yields (Volume of runoff in depth of inches) from a given storm use Figure 1. To use this chart the precipitation depth in inches and the soil-cover complex number is known. Locate the rainfall depth on the abscissa, move parallel to the ordinate until the soil-cover complex curve number is intercepted, then move parallel to the abscissa to the ordinate and read the runoff in depth of inches. Runoff depth in inches is converted to acre feet per section by multiplying depth in inches by 53.33.

Acre feet per sq. mi. = runoff depth x 53.33

Technical Paper No. 40, Rainfall Frequency Atlas for the United States, by the Weather Bureau, Department of Commerce, gives a series of isohyetal maps. The isohyets represent rainfall in depth by inches. In comparing the rainfall represented by the isohyets for the various storm frequencies for Idaho, we find that they are far below records of the Agricultural Research Service for the Reynolds Creek Experimental Watershed. By multiplying the depth in inches taken from the isohyetal map for Idaho for a given storm frequency and duration

concentration will be computed. In this case it will be computed from the upper reach to the first point, first point to second point, second point to third point, etc. The time of concentration at the last point will be the sum of the time portions to the points. Time of concentration (Tc) between any two points is computed by the following formula:

$$Tc = \frac{L}{3600 \; V}$$

Tc = time in hours

L = length between the two points in feet

3600 is number seconds per hr.

V = velocity - rate of travel in feet per second

The velocity computed from field data on stream flow (Cuyahoga notes) for each stream section is used to compute time of concentration.

9 Isohyetal Map

Lines can be drawn on a map to represent equal precipitation depth in inches. These lines are called isohyets. A map containing isohyets or lines which show equal precipitation for a given area is an isohyetal map. Isohyets are to rainfall depth as contours are to elevations.

Isohyetal maps for a 6-hour storm with frequencies of 10, 25, 50, and 100 years are given in the appendix. These should be used in estimating rainfall in inches for a given storm frequency in a given watershed. State Office engineers may make the map more detailed to increase the accuracy of estimates by drawing more isohyets provided it is done with the concurrence of the Weather Bureau.

10 Water Yield from a Storm of a Given or Designated Rainfall Depth

To determine water yield (inches of runoff or depth of runoff) from a given storm use figure 1. To use this chart the precipitation depth in inches and the soil-cover complex number is known. Locate the rainfall depth on the abscissa, move parallel to the ordinate until the soil-cover complex curve number is intercepted, then move parallel to the abscissa to the ordinate and read the runoff in depth of inches. Runoff depth in inches is converted to acre feet per square mile by multiplying depth in inches by 53.33.

Acre feet per sq. mi. = runoff depth x 53.33

Technical Paper No. 40, Rainfall Frequency Atlas for the United States, by the Weather Bureau, Department of Commerce, gives a series of isohyetal maps. The isohyets represent rainfall in depth of inches. In comparing the rainfall represented by the isohyets for the various storm frequencies for Idaho, we find that they are low when compared to the Agricultural Research Service (ARS) data recorded at Reynolds Creek Experimental Watershed. By multiplying the depth in inches taken from the isohyetal map for a given storm frequency and duration

by 2, we find the results to approach the rainfall to be expected in Idaho. Therefore, any rainfall depth in inches selected from an isohyetal map in Technical Paper No. 40 for Idaho, will be multiplied by 2 to obtain a rainfall depth in inches. The rainfall obtained in this manner will be used with Figure No. 1 to arrive at the direct runoff in inches.

For major earth structures the isohyetal map "50-year 24-hour Rainfall" or the "100-year 24-hour Rainfall" should be selected to compute rainfall depth in inches for use with Figure 1 in determining runoff in depth by inches.

11 <u>Peak Runoff</u>

The structures for water management in community watersheds are generally designed to handle a 50-year frequency storm. In a few special cases this may be increased to a 100-year frequency storm. Because the structures will be subjected to inflows from storms greater than the frequency for which they were designed it is important that they be designed to discharge the excess through an emergency spillway.

Spillway designs are based on peak flows. Therefore, the peak rate of runoff from a storm of a given frequency is determined prior to the design of a water control structure. The peak rate equation developed by the Soil Conservation Service is used in computing the peak rate of flow.

$$q_p = \frac{484\ A\ Q}{\frac{D}{2} + .6Tc}$$

q_p = Peak rate of flow in c.f.s.

A = Drainage Area in sq. miles

Q = Runoff in inches

D = Rainfall excess period in hours

D's relation to Tc is expressed by $D = 2\sqrt{Tc}$

$$q_p = \frac{484\ A\ Q}{\frac{2\sqrt{Tc}}{2} + .6Tc} = \frac{484\ A\ Q}{\sqrt{Tc} + .6Tc}$$

PROBLEM - The Fifteen-Mile Community Watershed plan shows that a detention dam will be constructed on an 8-mile tributary of 15-Mile Creek. Compute the volume of water to pass the dam site and the peak rate of flow at the point.

STEP ONE - Prepare the Data Sheet - Hydrologic Cover Condition and Soil Groups (Illustration 1). Instructions are in sections 3 and 4.

STEP TWO - In most watersheds there will be more than one vegetative type and likely two or more hydrologic condition classes in a type. Therefore,

a weighted average will have to be computed. Work sheet - Weighted Soil-Cover Complex Numbers (Illustration 2) provides a systematic manner for determining the weighted soil-cover complex number.

STEP THREE - Compute time of concentration which is discussed in section 8. Use work sheet, Illustration 3 in making computations.

STEP FOUR - Compute peak flow estimates from stream survey data. Use the Manning formula.

$$V = \frac{1.486}{n} R^{2/3} S^{\frac{1}{2}}$$

STEP FIVE - By the use of Technical Paper No. 40, Rainfall Frequency of the United States, find the rainfall in inches for a 6-hour storm of a 50-year frequency. Record the depth on Work Sheet, Illustration 4.

STEP SIX - Determine the direct runoff from Figure 1. Use of the chart Figure 1 is described in section 10. Record the data on Work Sheet Illustration 4. Compute acre feet per square mile, see section 10 and record on Illustration 4.

STEP SEVEN - Compute the peak flow. Use the peak flow formula based on the relationship of water yields to rainfall excess period and time of concentration. The formula is given in section 11. Use Work Sheet (Illustration 4) to make computation.

12 Hydrograph - Triangular

The triangular hydrograph is a simple graphic presentation by which one can easily grasp the units of runoff - peak rate, time of peak, volume of runoff and duration of runoff. Therefore, one should be prepared for each problem requiring peak rate of flow. The following equations are used for computing the units required for plotting the hydrograph.

$$T_p = \frac{D}{2} + L$$

T_p = Time of peak

D = Runoff excess in hours

D's relation to Tc is expressed by $D = 2\sqrt{Tc}$

L = Lag, time from center of excess to time of peak, hrs.

L's relation to Tc is expressed by $L = .6Tc$

T_b = Time base of hydrograph

$$T_p = \frac{2\sqrt{Tc}}{2} + .6Tc = \sqrt{Tc} + .6Tc$$

a weighted average shall have to be computed. Work Sheet - Weighted Soil-Cover Complex Numbers (Illustration 3) provides a systematic manner for determining the weighted soil-cover complex number.

STEP THREE - Compute time of concentration ratio is discussed in section 8. Use work sheet, Illustration 3 in making computations.

STEP FOUR - Compute peak flow estimates from stream survey data. Use the Manning formula.

$$Q = \frac{1.486}{n} R^{2/3} S^{1/2}$$

STEP FIVE - By the use of Technical Paper No. 40, Rainfall Frequency of the United States, find the rainfall in inches for a 24-hour storm of a 25-year frequency. Record the depth on Work Sheet, Illustration 4.

STEP SIX - Determine the direct runoff from Figure 1. Use of the chart Figure 1 is described in section 10. Record the data on Work Sheet Illustration 4. Compute acre feet per square mile, see section 10 and record on Illustration 4.

STEP SEVEN - Compute the peak flow. Use the peak flow formula based on the relationship of water yield to rainfall excess period and time of concentration. The formula is given in section 14. Use Work Sheet (Illustration 4) in making computation.

12 Hydrograph - Triangular

The triangular hydrograph is a simple graphic presentation by which one can easily grasp the value of runoff - peak rate, time of peak, volume of runoff and duration of runoff. Therefore, one should be prepared for each problem requiring peak rate of flow. The following equations are used for computing the basic triangle for plotting the hydrograph.

$$T_p = \frac{D}{2} + L$$

T_p = Time of peak

D = Rainfall excess in hours

D's relation to Tc is represented by $D = 2\sqrt{T_c}$

L = Lag, time from center of excess to time of peak, hrs.

L's relation to Tc is expressed by $L = .6T_c$

T_b = Time base of hydrograph

$$T_b = \frac{2.67D}{2} + .6T_c$$

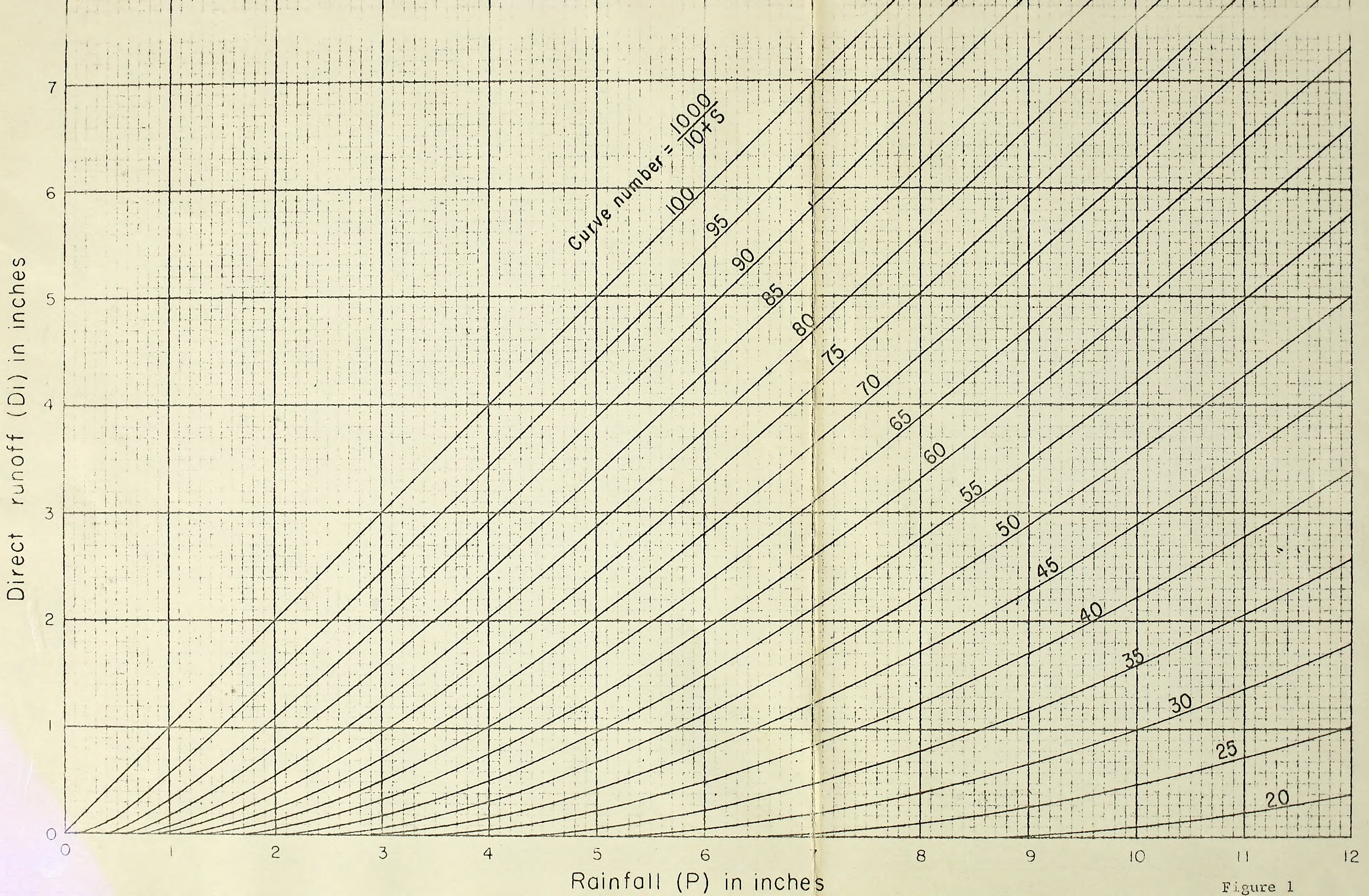
$T_b = 2.67\ T_p$

Plot hydrograph for the problem after section 4.11

$T_p = \sqrt{Tc} + .6Tc = \sqrt{1.16} + 6x1.16 = 1.78$ hrs.

$T_b = 2.67\ T_p = 1.78 \times 2.67 = 4.75$ hrs.

Plot the triangular hydrographs.



Curve number = $\frac{1000}{10+S}$
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
Direct runoff (Di) in inches
0
1
2
3
4
5
6
7
Rainfall (P) in inches
0
1
2
3
4
5
6
7
8
9
10
11
12

Figure 1

Table 1

Soil-Cover Complex Number for Rangelands

Cover Type	Hydrologic Condition	Hydrologic Soil Group				
		A	B	C	D	
Grass	Poor	64	79	86	89	antecedent II
	Fair	49	69	79	84	
	Good	39	61	74	80	
Sagebrush Grass	Poor	-	81	90	-	antecedent III
	Fair	-	66	83	-	
	Good	-	55	66	-	
Juniper-pinón	Poor	-	87	93	-	antecedent III
	Fair	-	73	85	-	
	Good	-	65	77	-	
Brush	Poor	63	79	86	95	
	Fair	51	63	77	88	
	Good	40	59	69	79	
Non-commercial Woodlands	Poor	48	69	83	94	
	Fair	39	61	74	86	
	Good	25	56	70	77	

Work Sheet | Illustration 1

Hydrologic Cover Condition and Soil Groups

Drainage Basin ______________________ Date ______________

Use of data ________________________

Vegetative types	Acreage	Hydrologic Condition	Hydrologic Soil Group
Sagebrush Grass	3,000	poor	C
" "	1,350	fair	C
Herbaceous	1,450	fair	C
"	680	poor	D
Total acres	6,480		

Work Sheet Illustration 2

Weighted Soil-Cover Complex Numbers

Drainage Basin ______________________

Use of data ______________________

Date ____________________

Hydrologic Soil Group (1)	Soil Cover Complex No. (2)	Area in Acres (3)	Col. 2 x Col. 3 (4)
C	90	3,000	270,000
C	83	1,350	112,050
C	77	1,450	111,650
D	95	680	64,600
Total		6,480	558,300

Weighted Soil-Cover Complex No. $= \dfrac{\text{Total in Column 4}}{\text{Total in Column 3}}$

" " " " " $= \dfrac{558300}{6480} = 86.15$ use 86

Work Sheet Illustration 3

Time of Concentration

Point Location ______________________________

Data Reference ____________________________________
Field Survey and investigation notes, etc.

Computed estimate of average velocity in ft. per sec. of flow in channel from point of beginning to location point (structure site, etc.) __________ft./Sec.

Time of concentration in hrs. $T_c = \dfrac{\text{hydraulic length of drainage (L) ft.}}{3600 \times \text{rate of flow (V) in ft./Sec.}}$

$$T_c = \frac{L}{3600 \times V} = \_\_\_\_\_\_\_\_ = \_\_\_\_\_\_\_\_$$

Peak Flow computed by use of Manning Formula (See Section 7)

$$V = \frac{1.486}{n} R^{2/3} S^{\frac{1}{2}}$$

$$V = \underline{1.486} \times \_\_\_\_^{2/3} \times \_\_\_\_^{\frac{1}{2}} = \_\_\_\_\_\_\_\_ \text{ft./sec.}$$

Peak flow $q_p = A \times V =$ ________ x ________ = ________c.f.s.

Volume Runoff - Peak Flow

by

Use of Chart, Figure 1, and Technical Paper No. 40, by Department of Commerce, Weather Bureau (See Secion 10)

Rainfall in inches from a__hour storm with a frequency of___years __________

(Take the rainfall from Technical Paper No. 40)

Runoff depth in inches ________ x 2 = ________

Volume of runoff in acre feet

Acre feet = Runoff depth in inches x 53.33

Acre feet per sq. mi. = __________ x 53.33 = ______________

Peak flow expressed in c.f.s. (Use peak flow formula, see section 11)

$$q_p = \frac{484\ A\ Q}{\frac{2\sqrt{Tc} + .6Tc}{2}} = \frac{484 \times \_\_ \times \_\_}{\frac{2\sqrt{\_\_} + .6\_\_}{2}} = \_\_\_\_\_\_ \text{c.f.s.}$$

TYPICAL NAMES OF SOIL GROUPS	GROUP SYMBOLS	IMPORTANT PROPERTIES				RELATIVE DESIRABILITY FOR VARIOUS USES											
						ROLLED EARTH DAMS			CANAL SECTIONS		FOUNDATIONS		ROADWAYS				
													FILLS				
		PERMEABILITY WHEN COMPACTED	SHEARING STRENGTH WHEN COMPACTED AND SATURATED	COMPRESSIBILITY WHEN COMPACTED AND SATURATED	WORKABILITY AS A CONSTRUCTION MATERIAL	HOMOGENEOUS EMBANKMENT	CORE	SHELL	EROSION RESISTANCE	COMPACTED EARTH LINING	SEEPAGE IMPORTANT	SEEPAGE NOT IMPORTANT	FROST HEAVE NOT POSSIBLE	FROST HEAVE POSSIBLE	SURFACING
Well-graded gravels, gravel-sand mixtures, little or no fines	GW	pervious	excellent	negligible	excellent	—	—	1	1	—	—	1	1	1	3
Poorly graded gravels, gravel-sand mixtures, little or no fines	GP	very pervious	good	negligible	good	—	—	2	2	—	—	3	3	3	—
Silty gravels, poorly graded gravel-sand-silt mixtures	GM	semi-pervious to impervious	good	negligible	good	2	4	—	6	4	8	4	4	9	5
Clayey gravels, poorly graded gravel-sand-clay mixtures	GC	impervious	good to fair	very low	good	1	1	—	3	1	2	6	5	5	1
Well-graded sands, gravelly sands, little or no fines	SW	pervious	excellent	negligible	excellent	—	—	3 if gravelly	6	—	—	2	2	2	4
Poorly graded sands, gravelly sands, little or no fines	SP	pervious	good	very low	fair	—	—	4 if gravelly	7 if gravelly	—	—	5	6	4	—
Silty sands, poorly graded sand-silt mixtures	SM	semi-pervious to impervious	good	low	fair	4	5	—	8 if gravelly	5 erosion critical	3	7	8	10	6
Clayey sands, poorly graded sand-clay mixtures	SC	impervious	good to fair	low	good	3	2	—	5	2	4	8	12	6	—
Inorganic silts and very fine sands, rock flour, silty or clayey fine sands with slight plasticity	ML	semi-pervious to impervious	fair	medium	fair	6	6	—	—	6 erosion critical	6	9	10	11	—
Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays	CL	impervious	fair	medium	good to fair	5	3	—	8	3	5	10	5	7	—
Organic silts and organic silt-clays of low plasticity	OL	semi-pervious to impervious	poor	medium	fair	8	8	—	—	7 erosion critical	—	11	11	12	—
Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts	MH	semi-pervious to impervious	fair to poor	high	poor	9	9	—	6	—	8	12	12	13	—
Inorganic clays of high plasticity, fat clays	CH	impervious	poor	high	poor	7	7	—	10	8 volume change critical	6	13	13	8	—
Organic clays of medium to high plasticity	OH	impervious	poor	high	poor	10	10	—	—	—	10	14	14	14	—
Peat and other highly organic soils	Pt	—	—	—	—	—	—	—	—	—	—	—	—	—	—

Engineering use chart